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16. Abstract

The main objectives of this study were to propose warranting conditions, to identify operational considerations and to prepare implementation guidelines for the development of flyovers. This has been accomplished. Also, it has been demonstrated that flyovers can increase the capacity of congested arterial intersections in a cost effective manner.

A relationship has been developed between average approach volume over the design life of the project and benefits. Projects with an average approach volume of 50,000 vehicles per day generate benefits of $6.5 million which is greater than typical costs of about $5 million dollars. Implementation of several flyovers in Texas would be appropriate to substantiate their benefits and provide an impetus for further use of the concept.

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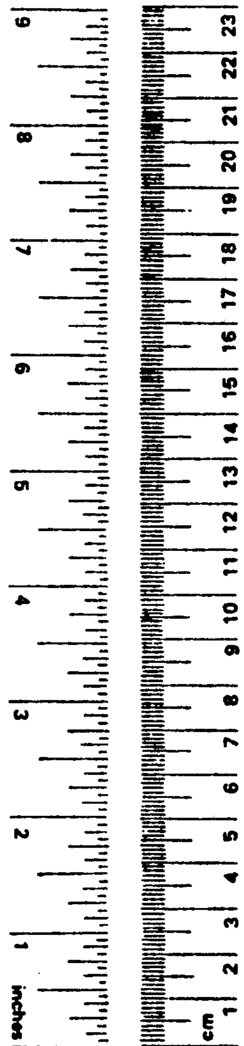
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
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mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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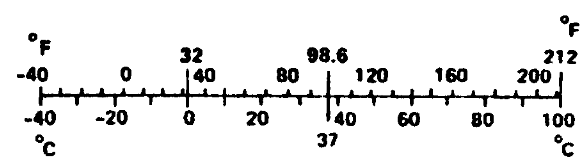
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



INCREASED CAPACITY OF HIGHWAYS AND ARTERIALS THROUGH THE USE OF ARTERIAL FLYOVERS

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Research Report Number 376-1
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SUMMARY

One intersection constituting a bottleneck on an arterial can significantly reduce the through traffic capacity of the whole arterial. The flyover, a grade-separated structure to divert through traffic over an at-grade intersection, can remove that limitation in a cost effective manner. Commonly, maximum use of the surface right-of-way has been made at bottleneck intersections. Taking additional right-of-way to widen the intersection is often considered but frequently deferred or rejected because it is contrary to arterial objectives, expensive and/or time consuming. Grade-separation may be a reasonable option.

The benefits of a flyover are dependent on the amount of traffic diverted from the at-grade intersection and on the ability of the modified intersection to handle remaining at-grade traffic. Benefits of nine potential flyover sites in Texas have been estimated making use of the PASSER II-84 computer program and a simple spreadsheet program. Flyover concepts have been developed to satisfy current and future traffic demand within the existing right-of-way.

A relationship was found between flyover benefits and the average approach volume of the current plus 20 year forecast. It appears that an average approach volume of 50,000 vehicles per day results in flyover benefits of about $6.5 million. A low type four-lane flyover built with conventional construction methods is estimated to cost about $5.0 million, including delay and diversion of arterial traffic during construction. Such a flyover can be justified based on a benefit to cost ratio that exceeds one.

Two major methods of flyover construction have been identified and their advantages and drawbacks discussed. These are the conventional, cast in place structure and the prefabricated, assembled at-site structure. The first generally costs less but construction takes from 18 to 23 months, while the second may be more expensive but construction takes only 4 to 6 months. Aesthetics have been cited as an objection to both but stronger against some prefabricated ones.

IMPLEMENTATION STATEMENT

The main objectives of this study were to propose warranting conditions, to identify operational considerations and to prepare implementation guidelines for the development of flyovers. This has been accomplished. Also, it has been demonstrated that flyovers can increase the capacity of congested arterial intersections in a cost effective manner.

A relationship has been developed between average approach volume over the design life of the project and benefits. Projects with an average approach volume of 50,000 vehicles per day generate benefits of $6.5 million which is greater than typical costs of about $5 million dollars. Implementation of several flyovers in Texas would be appropriate to substantiate their benefits and provide an impetus for further use of the concept.

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Initial research for this study was conducted by William R. Stockton, currently with the City of Austin, at the request of District 15 of the Texas State Department of Highways and Public Transportation (SDHPT). This led to the two year study on arterial flyovers and frontage road/freeway grade separated ramps. Many persons from District 15 in San Antonio, District 12 in Houston, District 17 in Bryan, D-10 and other SDHPT offices, and the City of Austin provided willing support and guidance in the data selection and collection. Special appreciation is expressed to Robert Stone and Rick Denney for their guidance and assistance during the study. The general concern and opportune involvement of Phillip Wilson of the SDHPT and of Stanley Byington of the Federal Highway Administration are also acknowledged.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, U.S. Department of Transportation or of the Texas State Department of Highways and Public Transportation. This report does not constitute a standard, specification or regulation.

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INTRODUCTION

Decision makers are frequently confronted with the problem of a congested arterial intersection where maximum use of the surface right-of-way has been made but traffic demand exceeds capacity. This intersection may be a bottleneck that impairs functions of nearby intersections and reduces the overall capacity of the arterial it serves. Traffic and signal improvement options have been exhausted. Adjacent development makes it time consuming, expensive and contrary to the objective of improving access to acquire additional land. The problem remains indefinitely unless improvements are made within the existing right-of-way.

Flyovers may provide the solution to the dilemma. Conventional interchanges are often not a feasible option where adjacent property is fully developed because of the extensive right-of-way. An intermediate approach is to provide a flyover that fits within the typical arterial right-of-way. A flyover is a two-or-more lane structure on an existing arterial that overpasses a cross street. Since flyover traffic can move through an intersection without being stopped by a traffic signal, capacity per lane is about the same as that of free flow arterial through lanes. Grade separation of traffic is the only way to increase intersection capacity once surface treatments are exhausted.

The benefits of a flyover are very dependent on the amount of arterial traffic diverted from the at-grade intersection to the overpass, since those going through on the flyover will experience no delay by the signalized intersection. The reduced at-grade traffic also improves the quality of flow at the signalized intersection. Benefits are measured in terms of reduced user delay, reduced vehicle operating expense and improved safety.

Background

Flyovers are not a new concept. In the late 50's and early 60's Chicago built at least three arterial flyovers to improve capacity (Walker, 1966). The then called through-lane-overpass successfully removed congestion at the three intersections without impacting nearby ones, as will be explained in the next section. But building a flyover is not without drawbacks. Construction within the confines of existing right-of-way is costly, takes 18 to 24 months, creates a lot of traffic disruption and may be objected by the general public.

Recent publications recommend the use of prefabricated flyovers that are manufactured, assembled in the field, and made operational in 5 to 6 months (Byington, 1981). Impact to adjacent properties and delay and diversion of motorists during construction can be minimal compared to conventional construction methods. Yet, capital costs of prefabricated flyovers seem fairly high and limited information is available on the unit cost of these structures. Most of the documented experience on flyovers come from Europe, especially France and Germany.

Currently there is a need for a simple, easy to follow procedure to evaluate existing intersections to determine the feasibility of flyover development. The flyover concept does not appear to have been widely considered, although some interest has been expressed in Texas and California. Warrants have been proposed in the past but these are hard to quantify and perhaps based on notions prevalent 20 or more years ago. Right-of-way requirements need to be defined based on current traffic management and design standards. Analysis tools now available permit the use of warrants based on measures that can be compared with those available on other highway options.

During 1983, District 15 of the State Department of Highways and Public Transportation engaged the Texas Transportation Institute to investigate the feasibility of flyovers to reduce congestion at two critical state maintained intersections. The analyses performed projected savings to roadways, and investigated the impact on adjacent land uses. In one case, the analyses showed that the flyover could be cost effective while another case did not show much gain. These analyses provided useful results, yet they were very time consuming and costly due to the lack of a simplified procedure to determine the appropriateness of a flyover. As a result, this study was designed to provide quick analysis tools for screening and evaluating potential flyovers.

Study Approach

This research has investigated nine arterial intersections in Texas. These were selected to provide a cross section of intersection types operating at different levels of congestion. Traffic volumes, geometrics, available right-of-way, accidents and existing land use were investigated. Traffic projections were obtained from the State Department of Highways and Public Transportation (SDHPT).

The PASSER II-84 computer model was used to help analyze the benefits of building a flyover. The PASSER II model simulates delay and stops required of traffic going through an intersection. Savings were estimated comparing the cost to road users going through the at-grade intersection with and without the flyover installed. Traffic on the flyover was assumed to incur none of the delay associated with the signalized intersection. Based on results of the benefit analyses and estimated construction costs, minimum warranting conditions have been identified by the benefit-cost ratio for a range of arterial conditions.

Other issues that affect the selection and development of a flyover have been reviewed. These include upstream and downstream transitions, the impact on nearby driveways, crossing streets and auto access to adjacent property, lane geometrics and minimum safety clearances, pedestrian traffic affected by the flyover, signalization and turning lanes. Some of these factors have been analyzed using other research guidelines, but are assessed based on the unique characteristics of the flyover.

Finally, procedures have been prepared for the detailed analysis of potential sites. These enable the user to determine a) whether a flyover is warranted at a specific location, b) the flyover configuration including number of lanes on the flyover and at-grade, c) cost effectiveness of the flyover, and d) impact on adjacent properties and pedestrians.

LITERATURE REVIEW

A search for documented cases of flyover construction has been conducted. Emphasis has been made on selecting those where an economic assessment has been made to better understand the decision process leading to construction. Documentation of conventional flyovers, those cast in place and using a concrete slab as a running surface, is limited. Only documentation of cases in Chicago and proposed flyovers in Orange County, California, provide details on the evaluation process that is applicable to this research. Several publications have been found documenting prefabricated steel structures, praised because of the very fast erection process and minimum disruption to existing traffic. The French and the Germans appear to have the most extensive experience with this kind of structure but they have been built in many countries. Economic details, however, are limited.

The following flyover review addresses only simple grade separated ramps that move through-traffic over an intersection. These are two-way structures operating with two, four or six lanes and with a single approach at both ends. Typically, they resemble a diamond interchange but due to right-of-way limitations and typical arterial speeds, the length, width and lateral clearances are more restricted than on freeways.

Conventional Flyovers

The use of grade separation to solve arterial congestion in United States' cities has been proposed for at least two decades. The 1965 Blue Book (AASHO, 1965) already had criteria for "major 2-lane highway" overpasses specifying a minimum lateral clearance of 3.5 feet between the through-pavement and the barrier wall when safety curbs (1.0 feet wide) were used. On high volume roads, typical of urban arterials, such minimum lateral clearance was allowed with or without the safety curb. Photos and examples of arterial underpasses, having about the same constraints as flyovers, were incorporated in the 1973 Red Book (AASHTO, 1973). These were recommended as perhaps "the only means available for providing sufficient capacity at some critical intersections". The examples presented were "built to eliminate bottlenecks in congested areas". The resultant design was an improvement over the at-grade intersection although many of the cross section elements were considered less than desirable. Conventional flyovers, where part or most of the superstructure was built in place, were in use in Chicago as early as 1958. Elsewhere others have been built but little or no documentation is available. Table 1 presents six cases of conventional flyovers built on congested arterial intersections.

Chicago

Three examples in this city are particularly relevant to this study because of the limited right-of-way available along the arterial. In 1958 a two lane, two-way grade separated structure was opened to traffic on Archer Avenue, going over Ashland Avenue (Walker, 1966). The all steel flyover was built within an 80-foot right-of-way and provided at-grade lanes for turning traffic. Figure 1 shows a sketch of this flyover. The total roadway width is 24 feet including a one foot mountable raised median. Conventional illumination is provided on the flyover. The nearest traffic signal is approximately half a mile away and allows two lane traffic approaching the overpass to merge into one traffic lane.

Two other flyovers were built in Chicago during 1961 and 1963, each operating with four lanes, two in each direction. The concrete structure on Western Avenue going over Belmont has two 19.5 foot roadways separated by a 3-foot median. Figure 2 shows this facility. The spans are structural box beams and the running surface was originally two-inch thick bituminous concrete.

The Western-Belmont flyover was built within a 100-foot right-of-way. Traffic using the flyover bypasses the five-way intersection. Illumination is provided by lamps mounted on the guardrails. At-grade access lanes parallel to the flyover are 18 feet wide. A 16-foot wide parking access lane is incorporated under the structure. Figure 3 shows some of the geometrics.

The three intersections were a bottleneck on each arterial. However, with the flyover the capacity at these points on the arterial were increased between 114 to 300 percent, while the peak hour flows of nine intersection

Table 1. Existing Conventional Arterial Flyovers

Location	Year Built	Structure: Spans	Structure: Approaches	Lanes & Width	Total Length	ROW Width	Construction Time
1. Archer-Ashland, Chicago[1]	1958	Steel	Steel	2-11.5'	?	80'	?
2. Western-Belmont, Chicago[1]	1961	Concrete 11 spans	Concrete	4-9.75'	1691' 1100' Bridge	100'	?
3. Ashland-Pershing Chicago[1]	1963	Concrete 13 spans	Concrete	4-9.75'	1650' 1159' Bridge	100'	?
4. US-19 at SR 602 Clearwater, Florida	1973	Steel	Concrete	6-?	?	380'-400'	25 month
5. 10 Flyovers[3] Kuwait City, Kuwait	1978-79	Steel	Concrete (precast)	6-?	1560'	Expressway	7 month
6. Beverly Blvd over Glendale, Orange County[4]	?	Concrete & Steel	Concrete	4-?	?	122'	?

Source: [1]Walker, Charles R., "Warrants for Highway-Highway Grade Separations", Investigation of the Through Lane Overpass, Northwestern University, Illinois Cooperative Highway Research Project Program, Project IHR 55, September, 1966.

[2]Information provided by Lisa Mills from the Orange County Transportation Commission, Santa Ana, California, January 1985.

[3]Walford, D., "Precast Abutment for Kuwait Flyovers", Concrete, November 1980.

[4]JEF Engineering and Hollinden-Recker & Assoc., High Flow Arterial Concept Feasibility Study and Evaluation of Case Studies, prepared for the Orange County Transportation Commission. Santa Ana, California, May 17, 1982.

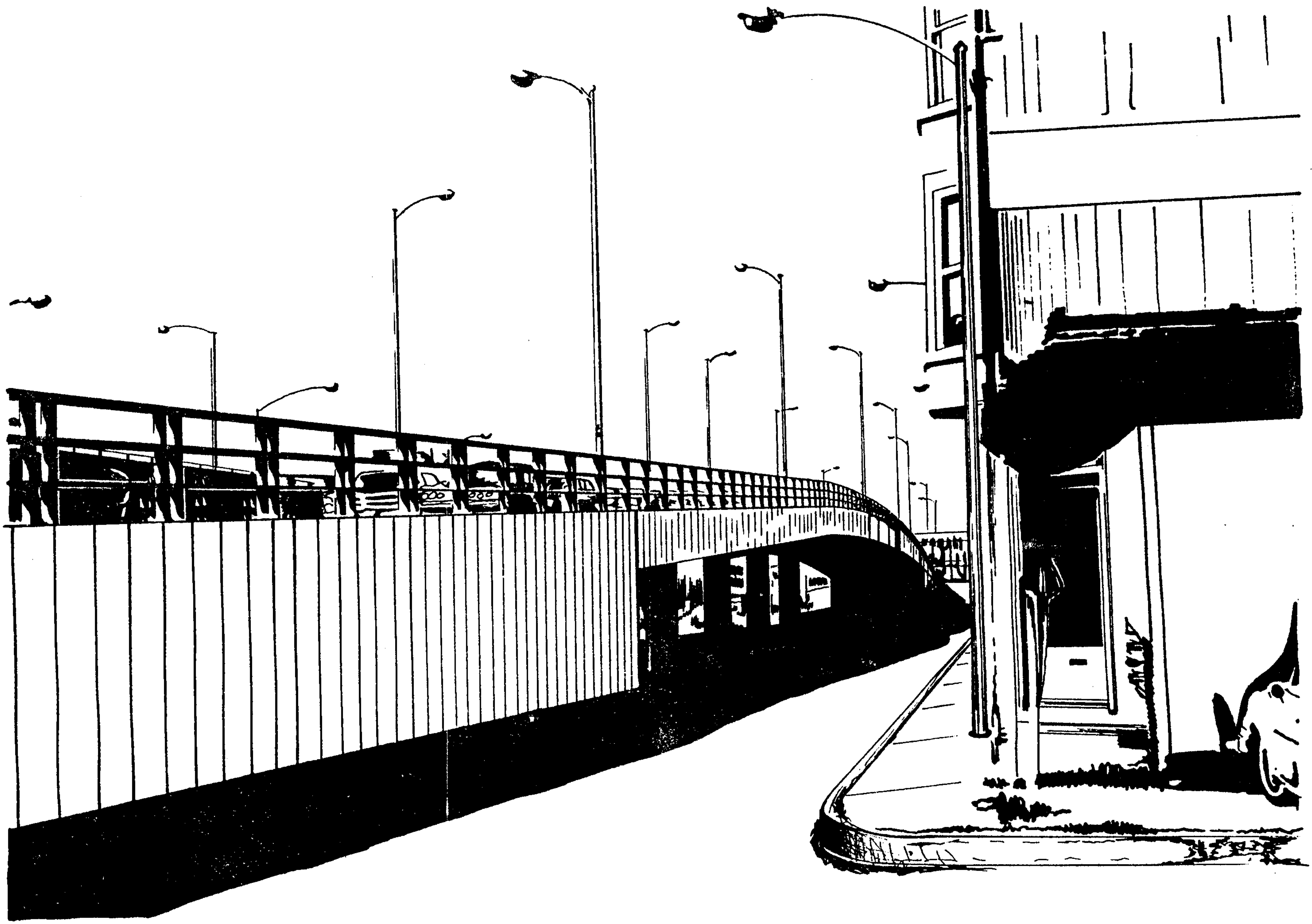


Figure 1. Archer Over Ashland Flyover, Chicago

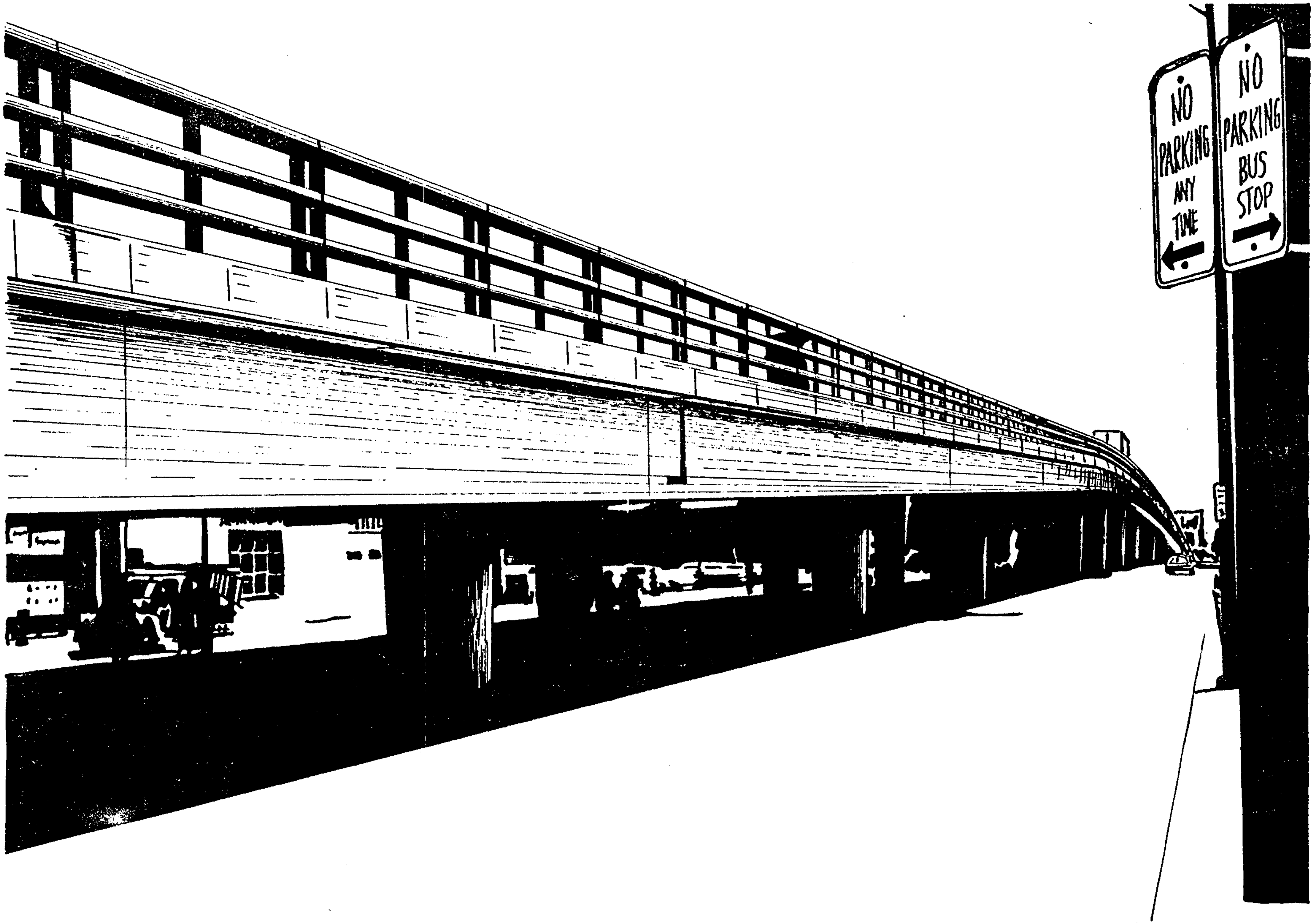


Figure 2. Western Over Belmont Flyover, Chicago

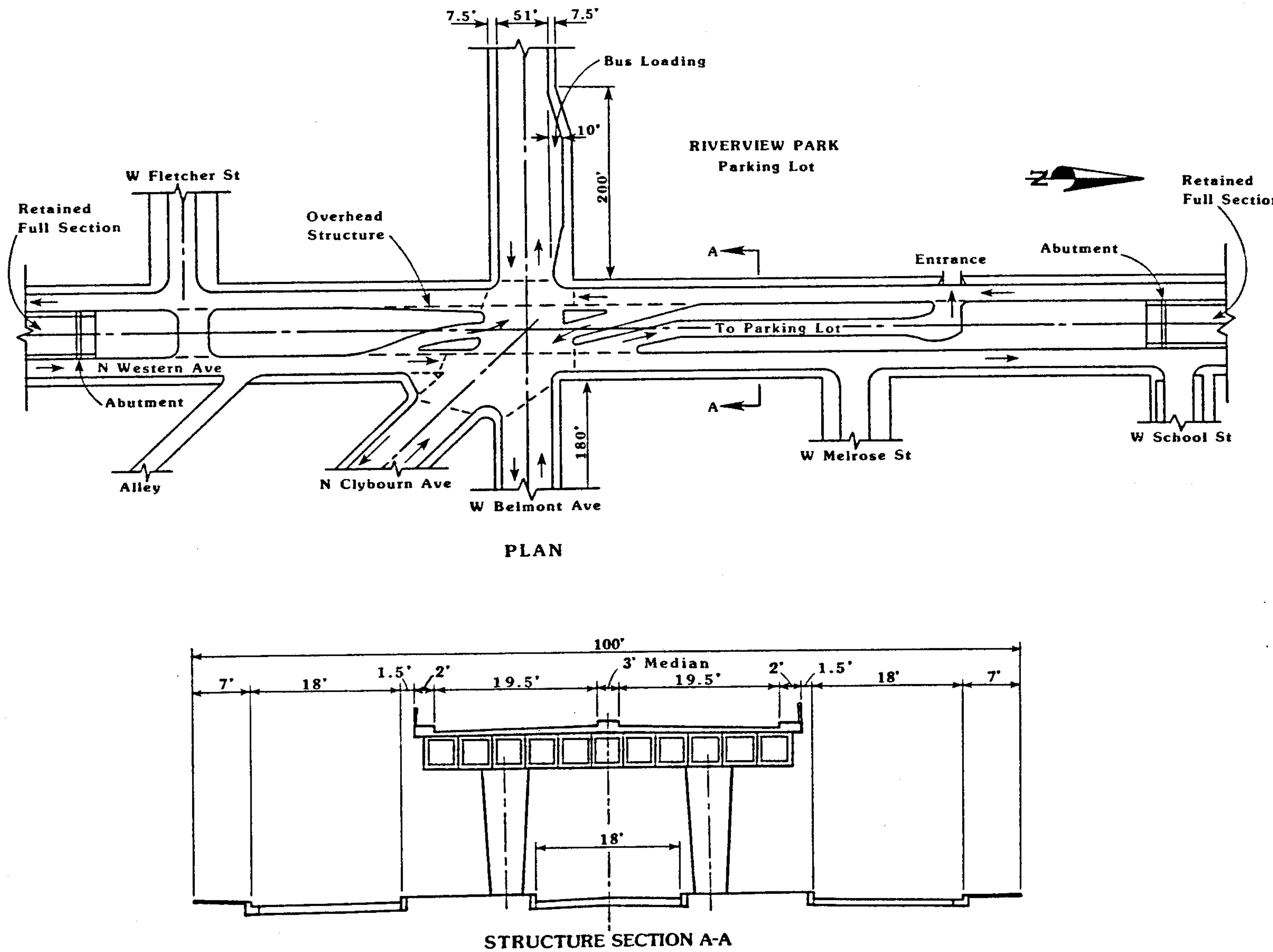


Figure 3. Geometrics of the Western-Belmont Flyover Intersection, Chicago

approaches went up by 33 percent, on the average (Walker, 1966). The Western-Belmont flyover experienced a reduction in delay, going from 82 seconds per vehicle to 17 seconds per vehicle along the arterial served, for peak hour savings of 80,000 vehicle hours per year. The Ashland-Pershing intersection accidents went down from 186 to 92 per year, or about 50 percent. Collision diagrams showed that opposing traffic accidents and cross street accidents, which tend to be the most serious, decreased from 13 to 1 during the same period. A financial analysis prepared on the Ashland-Pershing flyover indicated a benefit-cost ratio of 2.2, using economic factors prevalent at that time.

The design of the Ashland over Pershing structure is similar to that at the Western-Belmont intersection. This overpass also was built within a 100-foot right-of-way, but additional property was acquired on the cross street adjacent to the flyover to improve right turning movements. Turn arounds are provided under the structure to improve access to properties on both sides of the flyover . The paved section on Ashland is 70 feet wide as it approaches the flyover touchdowns. Figure 4 shows a sketch of this facility.

The three Chicago flyovers were built in already developed areas where commercial and manufacturing land uses were dominant. Typical of urban conditions, several building structures extended to the back of the sidewalk. Prior to their development there was concern on the economic impact that the flyovers may have on the adjacent properties. Land value analysis found that some property located at intersections with the overpasses increased less in value than at nearby intersections where no flyovers had been built (Walker, 1966). At the Western-Belmont intersection where commercial uses were dominant the value of two plots declined 30 and 33 percent. However, at the Ashland-Pershing intersection, where manufacturing was the principal land use, the flyovers did not seem to affect property values. It was concluded that "the through-lane overpass did improve land values and may have had an adverse effect on land zoned commercial. There was no evidence that manufacturing property was adversely affected".

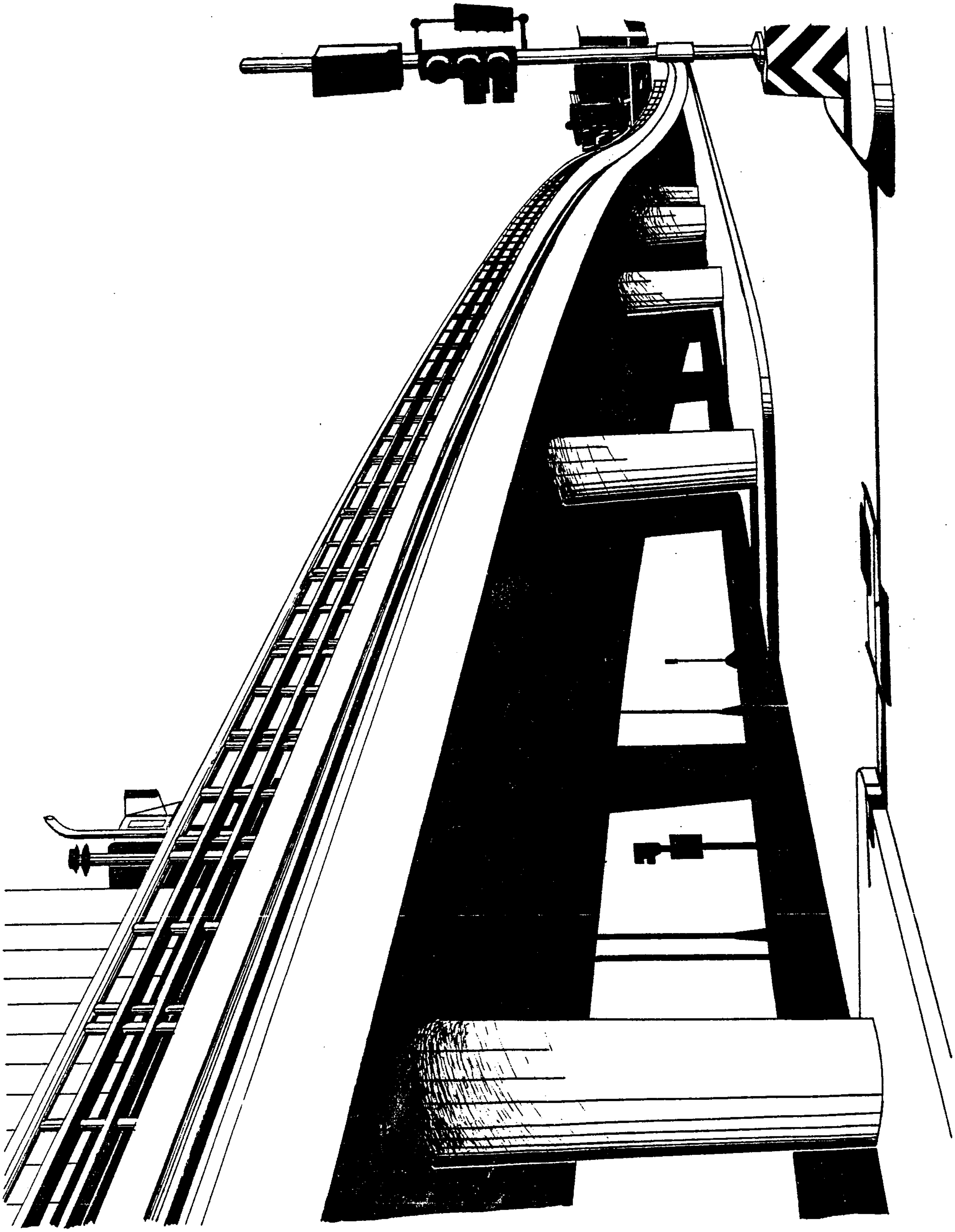


Figure 4. Ashland Over Pershing Flyover, Chicago

Clearwater, Florida

Another example of an arterial flyover was built on US 19 at State Route 60 (McCann, 1985). Although atypical in the sense that right-of-way width is about 400 feet, it was built to satisfy isolated intersection problems with approaches built on retained embankments. The bridge structure using a steel box beam girder spans 200 feet. Construction of the $3.4 million facility took two years and was completed in December, 1983.

Development existed on three of four corners at the intersection. Shopping centers occupied two corners while a motel/restaurant occupied the third. All driveway access were preserved, although some are restricted to right turns only. Several public hearings were conducted during project development with little opposition expressed. The structure was described as noisy but no complaints were reported; this was attributed to the deep setback from adjacent land users.

Kuwait

In Kuwait City, the "ring roads" circling the city were experiencing congestion four times a day due to the split-shift work hours which allow for a three hour afternoon break. In 1978 a contract was awarded to build nine prefabricated flyovers (Walford, 1980) as temporary structures. The program was to build the first structure within six months and thereafter, complete one per month. The expeditious construction of prefabricated steel flyovers was intended to alleviate traffic congestion prior to the implementation of the Kuwait motorway system, expected to be completed five years later.

Construction was scheduled to proceed as follows: (1) protect underground utilities and detour traffic, (2) build footings and receive steel bridge sections, (3) place in position and bolt together piers and cross beams while concrete abutments and retaining walls were precast, (4) install abutments and retaining walls on site, (5) backfill ramps, (6) place concrete barrier walls on ramp sides, (7) position girders at main span, (8) install deck grating and pour concrete infill, (9) lay asphalt and traffic markings.

Each bridge had six months programmed for construction leading to bridge opening to traffic, with an additional month allowed after opening for finishings.

This example makes extensive use of precast walls for the embanked approaches. The steel bridge was assembled of components bolted together. Although conventional in geometrics and materials, the construction method introduced prefabricated components that expedited construction significantly. The time to build these flyovers was 7 months or very close to that of the prefabricated type.

Typically each flyover is 1560 feet long with the steel bridge being 720 feet and the built-in-place approaches 840 feet. The bridge is comprised of 12 spans of 50-foot length and a central span about 125 feet long. Road width is 76 feet excluding barrier walls, allowing for three traffic lanes in each direction. Maximum longitudinal grade is 6 percent on the approaches to the bridge.

Orange County, California

As part of a feasibility study prepared for the Orange County Transportation Commission (JEF Engineering, 1982), a survey was undertaken to identify any flyover type structure that had been constructed in Southern California. Eleven grade separated arterial intersections were found and examined. Most of these involved typical diamond or loop type interchanges similar to those used on freeways. Yet, two locations, Beverly-Glendale and Ocean Park-Fourth Street, were found to have street geometrics and right-of-way widths similar to most Orange County arterials. These examples have design speeds of 35 to 45 miles per hour and could be constructed within the typical arterial right-of-way. The Orange County "Master Plan of Arterial Highways" classifies a major highway facility as having a 120-foot right-of-way.

The Beverly-Glendale intersection has the following characteristics. The bridge is 44 feet wide operating with two lanes in each direction. Two at-grade lanes in each direction allow for turning movements. Total right-of-way width is 122 feet, including sidewalks. Weaving distance in advance of the flyover is 200 feet while operating speed is 35 mph. One-way peak hour traffic was 1400 vehicles per hour on the flyover.

The Ocean Park-Fourth Street flyover, which is really an underpass, has similar design characteristics except that sidewalks, a painted median and bike lanes are included on the flyover. Right-of-way width is 140 feet, but it could have been narrower to fit within the typical arterial right-of-way.

Currently, Orange County is considering the use of flyovers in the "Super Street" program, together with other at-grade improvements including access limitation, parking restrictions, bus turnouts and intersection widenings along selected arterials. A network of such streets has been identified (Van Dell and Assoc., 1984) consisting of approximately 220 miles of existing arterials.

In December 1985 the Orange County Transportation Commission (OCTC) approved a program to improve Beach Boulevard between Pacific Coast Highway and Imperial Highway. Grade separations had been recommended at three intersections. However, the Huntington Beach and Buena Park City Councils voted in favor of intersection widenings at Warner Avenue and La Palma Avenue, instead of flyovers. The adopted improvements incorporate the acquisition of right-of-way at various corners to add turning lanes. The LaHabra City Council deferred action on the Imperial Highway flyover to wait for a more detailed engineering and environmental study (Parsons Brinckerhoff, 1986).

Prefabricated Flyovers

A fast to erect flyover has been used in various European countries, particularly France and Germany. This is called a temporary flyover, because it can be dismantled and reassembled elsewhere. The superstructure is made of prefabricated modular components and can be assembled in a few days. The whole project including foundation, utility adjustments, etc., is reported to take a few months (Koger, 1971; Byington, 1981). Compared with conventional construction methods that normally take from 18 to 24 months, temporary flyovers have an edge in reducing traffic and neighborhood disruption during construction as well as providing early benefits. A year savings in road user operating costs can help to justify some projects. When construction delay is considered, the attractiveness of prefabricated flyovers is more obvious.

Stanley Byington of the Federal Highway Administration provides an excellent review of advantages and disadvantages on the use of prefabricated flyovers. He discusses capacity, safety consideration, aesthetics and environmental issues, design loads and typical dimensions, erection time, and costs (Byington, 1981). Structurally, prefabricated flyovers have been promoted to be used as any conventional overpass. On the other hand, Byington cites R. Lapierre of the German Ministry of Transportation saying that "Flyovers (prefabricated) have always been regarded as a temporary and urgent measure for a period of five years until a complete and permanent reconstruction or improvement of an intersection could be realized". In any case, the extent and time of flyover usage seems more dependent on costs, traffic demand, safety, environmental and aesthetic considerations than on design characteristics.

Table 2 presents a selection of two-way temporary flyovers that have been installed in France and Germany. Although reports include various uses of flyovers, the ones included represent only those bypassing a typical four-legged arterial intersection. The examples have a bridge length varying from 511 feet to 1,164 feet, excluding the approaches at both ends. The structures in France have 4 lanes, two each way, and a total running surface width of 14 meters (46 feet). The standard lane width of the "Autopont" prefabricated module is 3.5 meters (11.5 feet). The structures from Germany have two or three lanes of varying width. Reported longitudinal roadway grades vary between 4 and 8 percent. The overall length of the Dusseldorf over Kreuzung flyover including approaches was reported to be 1,410 feet, of which the bridge constituted about 60 percent. Erection time of the steel bridge is generally reported in terms of hours or nights, giving an indication on the speed of field construction.

Table 2. Selected Prefabricated Arterial Flyovers in Europe

(Two-way Traffic Only)

Location	Bridge[1] Length (feet)	Lanes Width (feet)	Total Lanes	Maximum Grade (%)
1. Bezons (RN 192-308-311), France *	640	46	4	NA
2. Bordeaux (Quatre Pavillion), France *	663	46	4	NA
3. Issy-les-Moulineaux (Billancourt), France *	836	46	4	NA
4. Marseille (rond-point du Prado), France *	754	46	4	NA
5. Saint Chamond (RN498), France *	653	46	4	NA
6. Toulouse (place de la Croix de Pierre), France *	571	46	4	NA
7. Vienne (Carrefour de la Gere), France *	1,164	46	4	NA
8. Toulon (Carrefour L. Borgeois et Malon la Soviet Est), France *	571	46	4	NA
- two successive flyovers	735	46	4	NA
9. Munchen over Ludwigtrasse, Germany, 1966	1,017	25.4	2	8
10. Munchen over Ingolstadter, Germany, 1969	692	25.4	2	6
11. Berlin-Schonenberger over Dominicusstrasse, Germany, 1968	518	34.4	3	5.8
12. Berlin-Kinickendorf over Schumaker platz, Germany, 1968	974	23.0	2	4.8
13. Dusseldorf over Kreuzung Western, Germany, 1969	852	23.2	2	5.0

[1]Does not include retained ramps.

*Date of construction unknown.

Source: Lefranc, 1971; Idelberger, 1969.

Temporary flyovers can be used for other purposes including grade separated left turn lanes, one way lanes, viaducts, channeling traffic from an arterial to two different points (Wye-shaped). Their use is explained in various documents (LeFranc, 1971; Idelberger, 1969; Pleasants, 1980). Many specific locations of prefabricated flyovers have been identified in the literature including that of England, Italy, Spain, and Venezuela. Many are not restricted to limited right-of-way but practically all have been built where traffic congestion is severe and major detours are impractical. The cases following briefly explain procedures and characteristics of specific projects.

Germany

In 1968, a "fast assembly bridge" (Koger, 1971; Idelberger, 1969) was built in Hanover, to go over the Aegidientorplatz. At this location seven streets converge and five two-way tram lines passby. The flyover crosses four streets and three tram lines. This facility was built to relieve the area of one of the main traffic flows while ground level streets remained unchanged. The flyover bridge was scheduled for a 10-year use at that location.

The street bridge itself is primarily two lanes, with four access ramps. Total length is about 2,400 feet. The longitudinal grade varies from zero to six percent while the horizontal alignment is curved with a radius as tight as 300 feet. The roadway surface consists of an adhesive primer, a one-centimeter mastic layer and a two-centimeter melted asphalt layer. The mastic and the asphalt layers were applied after the bridge was erected. An ice signaling system was installed to warn a traffic service crew to sprinkle sand or clear the bridge.

The approach to eliminate an arterial bottleneck without severely disrupting traffic, was to erect a prefabricated steel bridge that could be quickly procured. The bridge was designed using standard components that could be manufactured and quickly put together in the field. The main element of the fast assembly bridge is the running platform manufactured in various sizes based on a standard module approximately 10 feet wide by 40 feet long. Foundation work, utility relocation and necessary traffic control measures are implemented prior to bridge erection.

Total time between order-to-proceed and opening of the flyover at the Aegidientorplatz was about 5 1/2 months, while fabrication and erection took about 4 months. Foundations and concrete ramps were built first. This was followed by the steel structure which took about 5 weekends to erect; work was done between 4 a.m. on Saturdays and 3 a.m. on Mondays. Even before the structure was completed, the melted asphalt had been layed over the steel deck. Koger reported that two years later the flyover was still in service without interruptions, and that it had been readily accepted by drivers, including bus and truck drivers.

Belgium

In 1975 two prefabricated flyovers were erected in Brussels, the first called AB-1 (Pleasants, 1980). This flyover provides three traffic lanes over a busy intersection. The main span is 117 feet long and total length, including approaches, is approximately 1400 feet. It was economically built using mostly standardized parts and precast concrete slabs. This bridge possesses the qualities of a permanent facility but can be dismantled, if needed. Expansion joints were located on the entry and exit side with no moving joints on the bridge proper. The foundation is of conventional design while the columns and cross beams were prefabricated. Standard and indentical concrete slabs rest on longitudinal steel beams to provide the road platform. A bituminous course on top of the concrete slabs provides the running surface. The steel beams are made continuous with rigidly bolted cover plates.

Construction barely impeded the flow of traffic. Traffic was channeled through the intersection while the foundations were being laid. Later, eight days were required for the erection of the bridge. Traffic on the bypassed lanes was held up for only four hours, and this took place between midnight and 4:00 a.m.

England

In Chiswick, London, a flyover was built over the Hogarth roundabout (Pleasants, 1980). Its design consists of two horizontal curves, one about 30 degrees to the left and another about 90 degrees to the right, to pick up cross traffic and direct it into London. This flyover was designed only for vehicles weighing no more than 3 tons, but for a life of 120 years. In practice, larger trucks make use of it and no effort is made to enforce the weight limit, other than by the sign over the entrance that reads "Limit 3 Tons". Another example exists on the Great Chertsey Road A-316 bypassing the Ellesmere A-4 westbound traffic to the Heathrow Airport but details are not available.

Results of Previous Studies

Of the several studies reviewed some deserve special attention as they address some study objectives. These are included below.

The initial High Flow Arterial Concept Feasibility Study in Orange County (JEF Engineering, 1982) evaluated four intersections to determine: 1) improvements to intersection level of service, 2) construction costs, and 3) impacts on adjacent properties. General findings of the study indicated that the installation of flyovers would reduce vehicle delay not only for the intersection involved but also for the intersection immediately downstream from the project. The downstream benefit was attributed to the dispersion of vehicle platoons that form as a result of traffic signal control. It is not clear that the study's conclusion is correct. It was also suggested that flyovers at highly saturated intersections together with signal optimization at the remaining intersections may offer the most cost effective solution to improve traffic flow along an arterial.

This study briefly considered the use of prefabricated flyovers. It was expressed that the rapid construction time of prefabricated structures offers considerable advantage over conventional methods at locations where the adjacent property is fully developed.

It was concluded that the advantages of flyovers are maximized when through movements are dominant, turning movements are comparatively low and turning lanes are not reduced. Construction cost, excluding right-of-way of a typical overpass averaged $2.5 million. Of the four study sites, only one would result in restriction to existing left turns into or out of adjacent intersections; however, this was a site specific condition.

An earlier study on the adequacy of flyovers to form junior expressway (super streets) or to remove bottlenecks (Walker, 1966) concluded that:

1. Through-lane overpasses in groups to form junior expressways do not compare favorably with expressways in providing corridor service. The expressway is superior to the junior expressway using through-lane overpasses in total transportation cost, accident rate, and level of service provided.
2. The overpasses are not aesthetically pleasing.
3. The overpasses do not improve land values at the intersections, and probably decrease them in commercial areas.
4. The capacity of the street with the overpass structure is greatly increased, but the capacity of the street passing under the overpass is not appreciably increased.
5. The overpasses remove bottlenecks from the arterial streets containing them.
6. The total traffic volume through the intersections with the overpasses increased in the order of 20 to 30 percent after the construction of the overpass; however, the total corridor flow was not increased due to capacity limitations at nearby intersections.
7. A large amount of delay and operating cost is saved by the overpasses. There was no evidence that this congestion was shifted to other locations.
8. The overpasses provided a 33 percent or greater reduction in intersection accidents.
9. The benefit in time, accident, and operating cost savings obtained by providing one of the overpasses in Chicago was about 1.7 times the required capital expenditure (in terms of present worth) over a 20 year period at 3.75 percent interest.

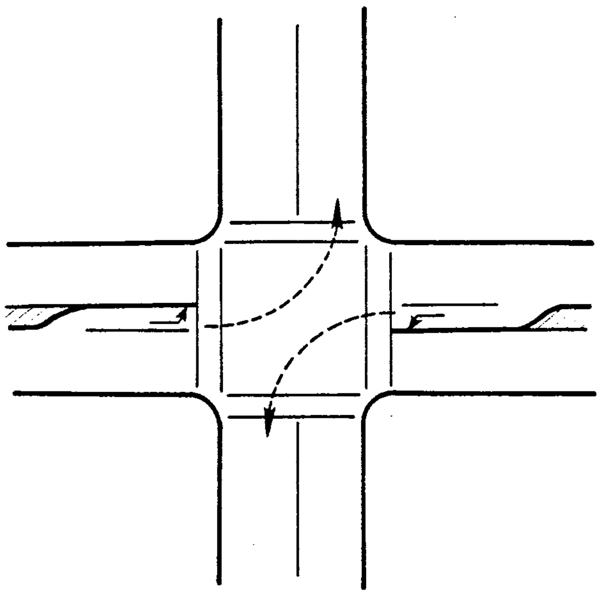
10. The through-lane overpass is a useful, effective and economical tool in reducing delay and accidents at a bottleneck location on a traffic corridor, but it will not increase the capacity of the corridor if there are nearby intersections with low capacity.

In regards to capacity, Byington reported that a study (LeFranc, 1971) of 9 two-lane, two-way flyovers built in France between 1970 and 1971 showed peak hour volumes of 2,500 cars or less. Of a total of 18 flyovers studied, 14 had surface street capacities equal to or in excess of 30 percent. The French study suggested that flyovers should not be considered as permanent unless there is a capacity reserve of 30 percent or more to accommodate future traffic growth.

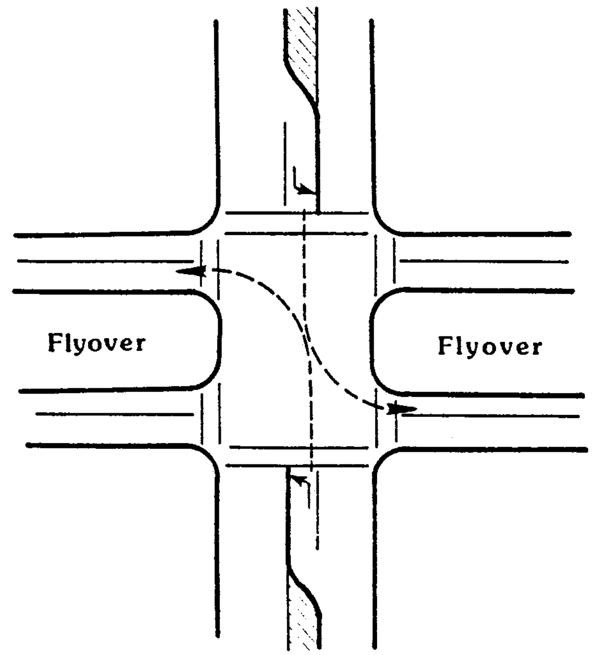
Flyover safety depends on the quality of signing at the entrance ramp. Europeans also enhance road markings by laying a continuous yellow line for 330-feet ahead of entrance ramps to separate opposing traffic streams (Byington, 1981). Rigid barrier dividers at entrance ramps can be protected with crash attenuators. Byington adds that structural supports must be carefully located to provide adequate sight distance on surface streets.

Simultaneous left turns from the arterial may not be possible with the flyover built. Arterials provided with medians typically provide aligned left turn lanes or pockets, as shown in Figure 5. Instead, the flyover structure requires some lateral displacement of arterial left turn lanes, bringing turning vehicles closer, and their paths may overlap. Diamond interchanges avoid these conflicts with separate turn lanes under the overpass. A California study (JEF Engineering, 1982) proposed three options to solve this problem.

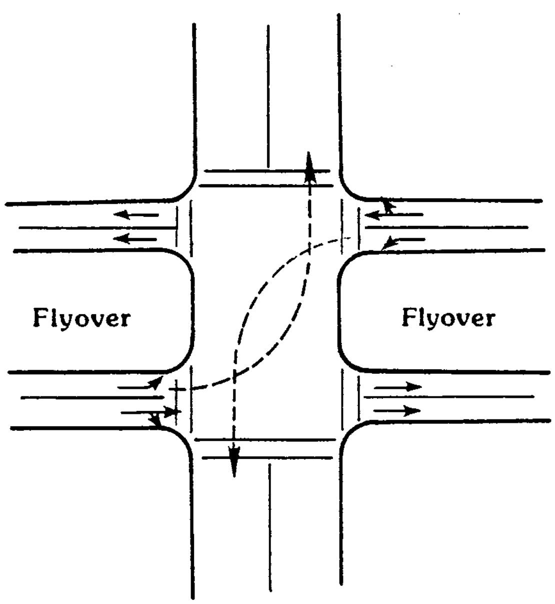
- Lengthen the mainspan to allow simultaneous left turns using very long radius curves,
- Prohibit simultaneous left turns by using a lead-lag signal phasing, and
- Design the bridge structure so that vehicles begin turning prior to entering the intersection.



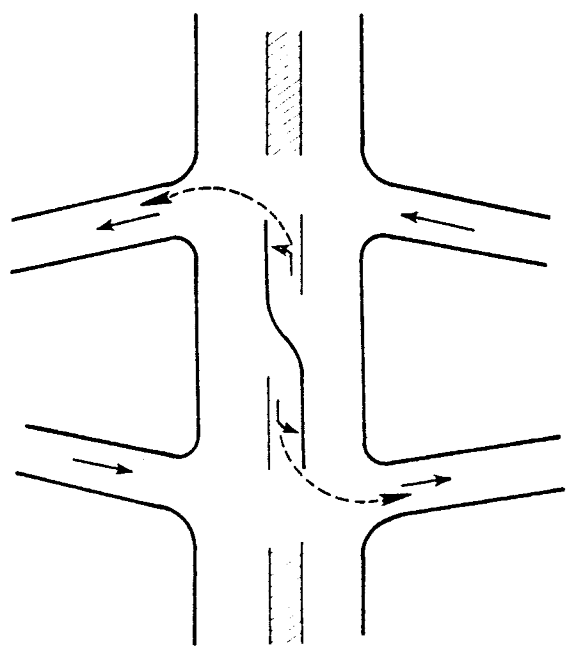
NORMAL SITUATION
Left Turn Pockets Aligned



FLYOVER
Left Turn in Direction of Cross Streets



FLYOVER
Left Turn in Direction of Flyover



DIAMOND INTERCHANGE

Figure 5. Conflicts of Simultaneous Left Turns

The third option is a potential solution if the structure is not too wide. Figure 6 shows how this can be achieved, tapering the ramp abutments into a bullet nose. The same treatment can be provided with an extended bridge on columns (viaduct), and may be preferred to allow continuous pedestrian access or to reduce visual impacts at the ground level.

The "Super Street" study in Orange County (Van Dell, 1984), proposed typical design criteria to assess a 220 mile network. This included:

Design Speed	35 mph
Maximum Grade	6 percent
Minimum Vertical Clearance	15 feet
Desirable Traffic Lane Width	12 feet

The above applied to a four-lane grade separation requiring at least 60 feet in width, with two at-grade lanes on each side. Minimum arterial cross-section was 120-feet and typical overpass length 1200 feet.

Early research (Walker, 1966) proposed that the following conditions be met to consider an arterial flyover.

1. Three moving lanes now are available in each direction along the arterial.
2. Adequate right-of-way is available with 100-foot right-of-way for a four-lane overpass, and 80-foot right-of-way for a two-lane overpass.
3. The bottleneck cannot be removed by standard traffic engineering methods because of space restrictions or other considerations.
4. The intersection is in an industrial, undeveloped, or low-type commercial area that would not be adversely affected by the overpass.
5. The intersection is now operating at capacity in peak hours.
6. The intersection's approach capacity is appreciably less than that of other typical signalized intersections on the arterial.

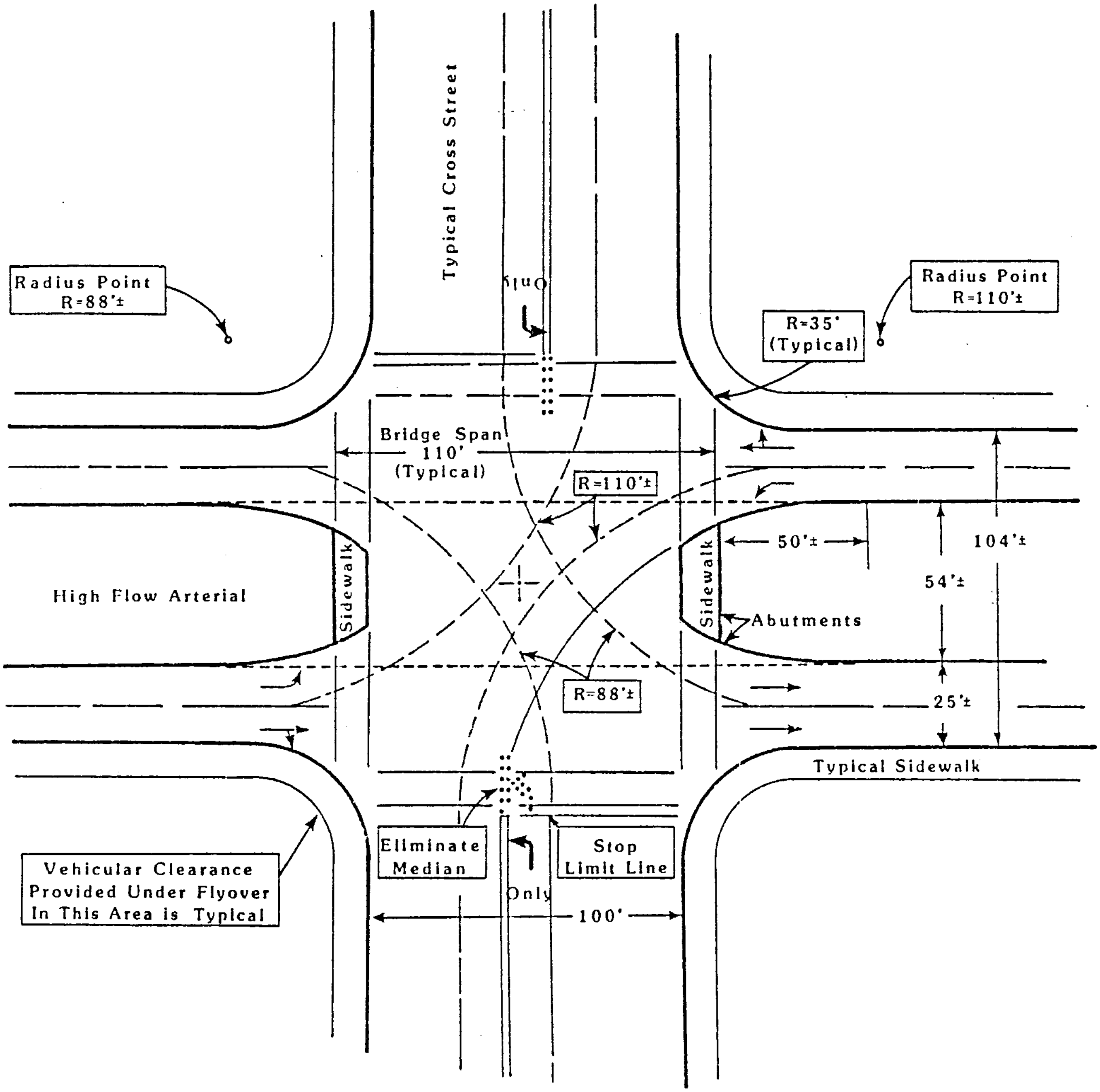


Figure 6. Optional Solution For Simultaneous Left Turns

Source: JEF Engineering, 1982

If the above warrants were met, it was proposed that a more detailed study of the particular intersection should have been made.

FLYOVER CHARACTERISTICS

Each intersection operates in a unique environment that requires design to match traffic needs. Design must consider the type of flyover structure, required at-grade improvements, signalization, utility relocation and traffic handling during construction. The first three are commonly defined early in the planning process because they are related to the improvements desired. Traffic handling and utilities are more uncertain at this level of analysis but will be discussed based on available information.

Design Concept

Flyover design characteristics have been determined for each case based on the concept geometrics required to satisfy demand while constraining each to the existing right-of-way. Number of lanes, length, width, turning lanes required under a structure, type of structure, utilities and construction related traffic handling costs have been considered.

Right-of-Way

With unlimited right-of-way there would be no need for a flyover, as a conventional interchange could be built. Flyovers are proposed for locations where an arterial intersection constitutes a bottleneck that conventional low-capital traffic engineering measures cannot resolve. Also, they have been proposed as an option to reduce the number and severity of accidents at critical intersections.

A minimum right-of-way must be available in order to benefit from the use of flyovers. Limited lateral (safety) clearances are a major constraint in determining lane width, capacity and safety. Each site may have unique characteristics but motorists expect uniform roadway geometrics. Since intersections considered for a flyover are usually operating with the maximum number of lanes allowed by the available right-of-way, sometimes there may not be adequate space to provide all the desirable safety clearances. Trade-offs must be made that result in a facility with marginal clearances, low type (desirable minimum) clearances, or high type clearances that include safety shoulders.

Table 3 presents the recommended minimum right-of-way for a given number of flyover lanes.

Table 3. Minimum Right-of-Way for Urban Arterial Flyovers

(feet)

	Two Lane	Four Lane	Six Lane
Marginal	76	98	--
Low Type	100	120	140
High Type	120	144	168

The marginal values represent flyovers with close to the minimum cross section possible for an urban arterial. These are not recommended cross sections except as a temporary measure or for exceptional cases. Right-of-way criteria has been derived from the minimum cross section of a hypothetical flyover, as shown in Figure 7. The low type represents a typical flyover operating with a partial shoulder on the right and allowing for other commonly used safety clearances and standard sidewalks. The high type width allows for full right shoulders on the flyover and design speeds above 45 mph. This concept would provide an 8-foot median with a concrete barrier. Various trade-offs are possible to adjust to specific locations and are best demonstrated through case study analysis.

Structure Length

The profile of a flyover is principally determined by the design speed, the vertical clearance required above the cross street and the span over the cross street. Design speed may be taken as posted speed unless the arterial is expected to be upgraded to a higher speed in the near future. Vertical clearance should be 16.5 feet but the nature of the cross street and nearby constraints may allow this to be reduced, but not below 14 feet. For the case studies a 16.5-foot clearance has been assumed along a 100-foot main-span.

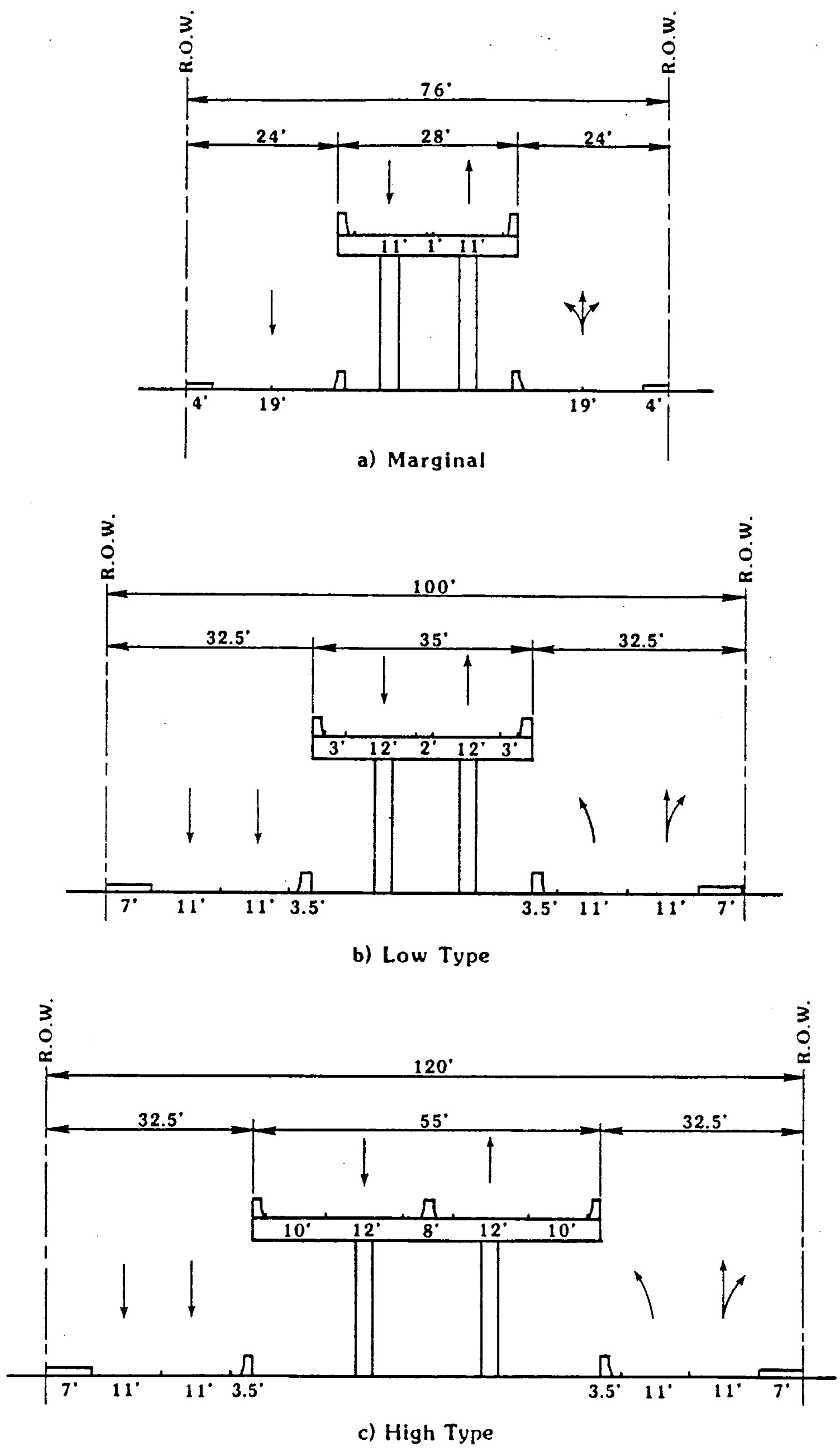


Figure 7. Minimum Cross-Section and Right-of-Way for a Two-Lane Flyover

Structure Width

The arterial cross section lateral clearances should be maintained or improved. Figure 7 shows the minimum cross section for marginal, low type and high type flyovers. Ideally, lanes should be 12-feet wide where consistent with the rest of the arterial. If the arterial has shoulders these should be continued on the flyover.

The structure width is mainly determined by the number of lanes, lane width and lateral clearances. A marginal flyover would operate with 10- to 11-foot lanes and zero to 1-foot lateral clearance to a curb, rail or other side barrier. Maximum speed would be 30 mph. A low type flyover would have 11- to 12-foot lanes, 3-foot wide shoulders and design speed not higher than 45 mph. The high type flyover would have 12-foot lanes, 8- to 10-foot shoulders and no speed limitations other than to be compatible with the arterial. Opposing traffic would be separated by a guardrail or barrier wall.

CASE STUDY

Seven cases were selected for analysis; Table 4 presents flyover characteristics for each case studied. Table 5 summarizes design characteristics.

Case 1 takes advantage of the topography of the area with the cross street on structure. Traffic volume requires 6 lanes (11 feet wide) for a total width of 94 feet. Figure 8 shows a cross section looking west toward the intersection. It should be noticed that a partially cantilevered left turn lane is required in order to accommodate traffic demand while remaining within the existing right-of-way. The eastbound traffic does not need such a structure because a wider right-of-way (200 feet) is available. The cross street bridge would be 88-feet wide. Overall length of the underpass is approximately 1821 feet with a maximum grade of 3.9 percent on the west approach. Utility relocation is expected to be very expensive, time consuming and disruptive of traffic.

Table 4. Geometric and Operating Characteristics of Study Sites

Case	R-O-W width	Design Speed (Posted Speed)	Average Daily Traffic[1] Arterial ADT	Average Daily Traffic[1] Cross-Street ADT	Arterial/ Cross-Street Ratio	Existing Arterial Thru Lanes	Flyover Lanes Desirable	Arterial Left Turn Lanes in use	Arterial Left Turn w/over 200 vph
1	160	60	69,411	37,454	1.85	6	6	2,2	748 EB
	200	(50)	(1983)	(1983)					219 WB
2	120	40	28,285	21,601	1.31	4	4	1,2	202 NB
		(40)	(1981)	(1981)					216 SB
3	200	60	80,532	6,898	11.7	6	6	1,1	--
		(50)							
4	120	35	65,630	21,680	3.03	8	4	1,1	--
		(35)							
5	165	45	42,810	21,189	2.02	4	4	1,2	384 WB
		(45)							
6	a 100	45	28,431	14,564	1.95	6	2	1,1	--
		(45)	(1982)	(1982)					
	b 100	45	30,861	14,599	2.11	6	2	1,1	--
		(45)	(1982)	(1982)					
	c 100	45	26,240	10,852	2.42	6	2	1,1	334 WB
		(45)	(1982)	(1982)					
7	152	35	32,356	14,875	2.18	4	4	1,1	--
		(35)	(1984)	(1983)					

[1]ADT counts for 1985, unless otherwise specified in parentheses.

Table 5. Case Study Design Characteristics

Case	ROW (feet)	Overpass Lanes	Design[1] Speed (mph)	Total Length (feet)	Structure Width (feet)	Left Turn Lanes Under	Utilities Work L-M-H-VH	Construction Traffic L-M-H-VH	Maximum Grade (%)
1[2]	160[3]	6	60	1821	88[4]	NA[5]	VH	H	3.9
2	120	4	40	1578[6]	60	1	H	H	6.1
3	200	6	60	2087	103	--	H	M	3.9
4	120	4[7]	35	1154	59	--	H	VH	6.0
5	165	4	45	1492	60	--	M	M	5.5
6	100	2[8]	45	1492	35	--[9]	M	M	5.5
7	152	4[10]	35	1204	60	--	L	L	6.0

[1]Same as posted speed except for Cases 1 and 3.

[2]Underpass due to topography.

[3]The eastside has 160' right-of-way while the westside has 200' right-of-way.

[4]The bridge span is 94' long.

[5]Left turn lanes are above the underpass; one of the two westbound left turning lanes requires a special structure as shown in Figure 12.

[6]Total length includes 230' extra for left turn lane under structure.

[7]Forecast demand would require 6 lanes but ROW limits to only 4.

[8]Two lanes may not be adequate based on forecast demand, but ROW constraints limits each structure to 2 lanes.

[9]Structure 6.a would have a left turn lane under the structure, for a total length of 1722'.

[10]Two lanes would be adequate based on demand but four lanes minimum are always provided un-unless constrained by ROW.

However, traffic handling during construction does not seem to present a major problem due to available right-of-way and a clear area east of the intersection beyond the right-of-way. The proposed cross section takes into consideration the likelihood that this arterial will be rebuilt into a freeway in the future.

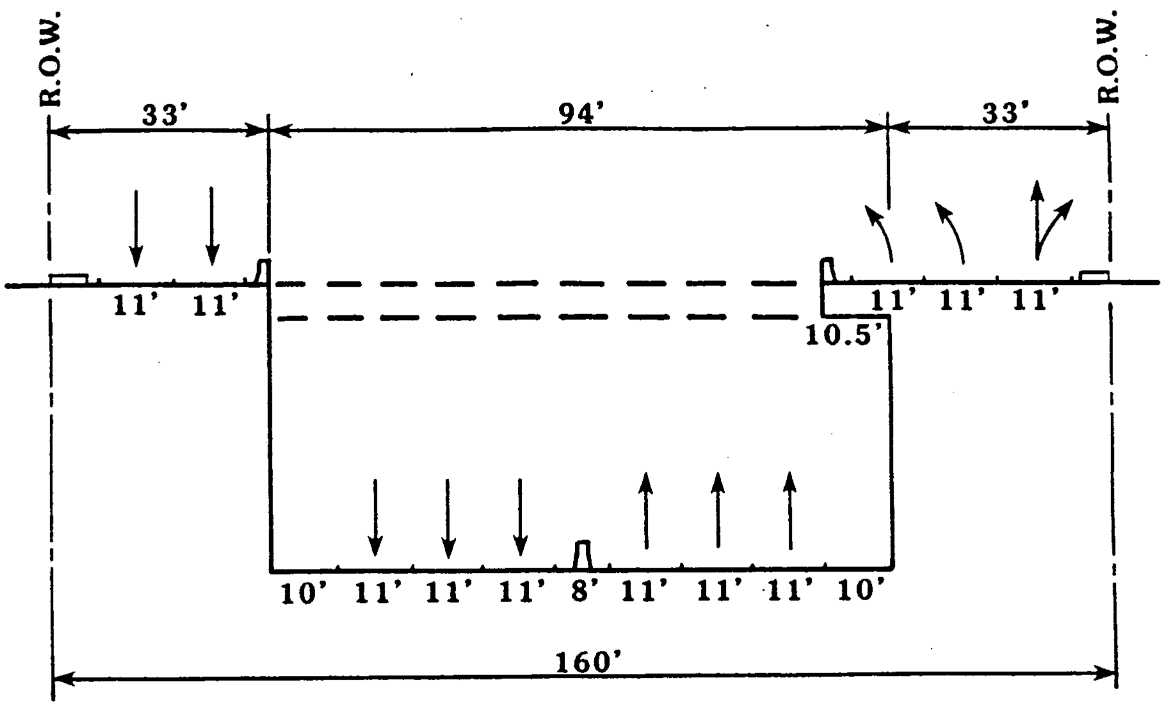
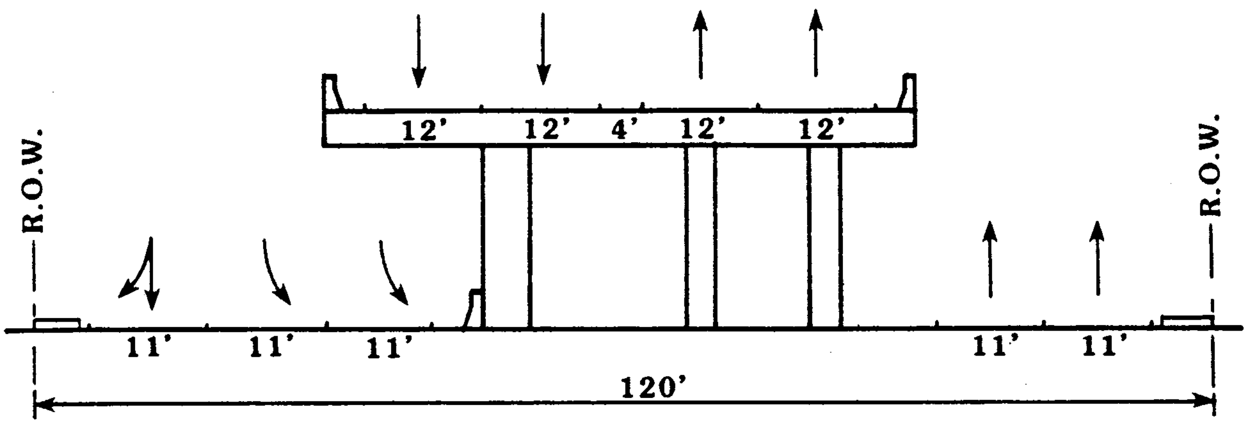
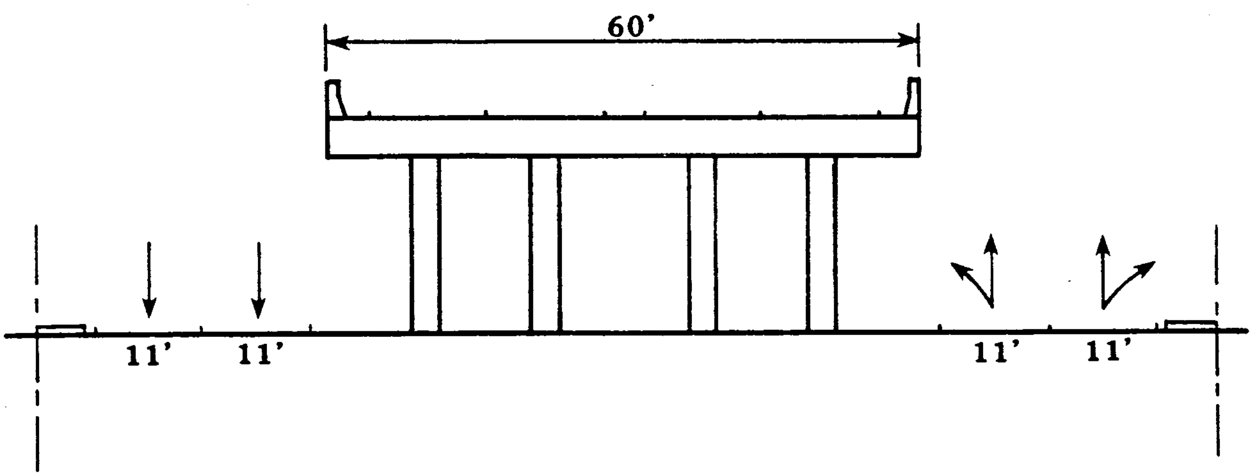


Figure 8. Case 1, US 183 at Burnet, Austin

Case 2 is a more typical case of an urban arterial flyover on restricted right-of-way (120-foot wide). Approximately half of the structure would be built on columns and half on embankment. This reduces the visual impact on adjacent properties and allows pedestrians to walk under the structure. However, this type of structure is somewhat more expensive than those using a simple bridge with retained ramps. To maximize the use of right-of-way all embankments are built with vertical-face retaining walls. This flyover uses 4 lanes each 12-foot wide for a total structure width of 60 feet. Figure 9 shows two cross sections of this flyover, one looking south toward the intersection and the second looking north. One southbound left turning lane is located under the structure to allow for current and future demands on this movement. This adds about 230 feet to the structure length (minimum) to



SECTION LOCATION: NORTH ON BURNET



SECTION LOCATION: SOUTH ON BURNET

Figure 9. Case 2, Burnet at Anderson Lane, Austin

maintain full vertical clearance along the lane while allowing up to 8 vehicles to stop for the signal. Overall length of the structure is estimated at 1578 feet and with a maximum grade of 6.1 percent. Utility relocation is expected to be expensive and disruptive to traffic. Traffic handling during construction may be difficult and some rerouting may be required. Access to adjacent properties needs to be maintained during construction. Details on impact to adjacent properties will be presented later.

Case 3 is a suburban flyover of an arterial bypassing a minor collector road. Except for a 100-foot long bridge at the intersection, the through lanes will be on embankment. Pedestrians can walk under the bridge to cross the arterial. The proposed cross section considers the probable construction of a freeway along this arterial right-of-way. The flyover uses six 12-foot lanes for a total structure width of 103 feet. Figure 10 shows the typical cross section of this concept, as would be observed looking north toward the intersection. Overall length is 2,087 feet, being the longest of those studied. Maximum grade is just 3.9 percent on both approaches. Utility relocation requirements are high but mostly for median drainage. Traffic handling during construction will be moderate even with the high traffic volumes using this intersection because of adequate right-of-way and possible rerouting of the low cross street traffic.

Case 4 is another typical case of an urban arterial flyover on restricted right-of-way (120-foot wide). Similar to Case 2, half of the structure would be built on columns and half on embankment. However, very high traffic demand would ideally use six through lanes but only 4 can be accommodated using standard low type design considered for this flyover. Proximity of nearby signalized intersections and heavy turning movements from the cross street also restrict the options available within the right-of-way. However, demand for this flyover may never be as high as projected unless arterial capacity is increased such as with additional flyovers. As designed, the four 11-foot lanes require a structure width of 59 feet. Figure 11 shows the typical cross section looking west toward the intersection. Overall length is 1154 feet long and maximum grades are 6 percent on both approaches. Utility relocation seems to be very difficult, expensive, and time consuming.

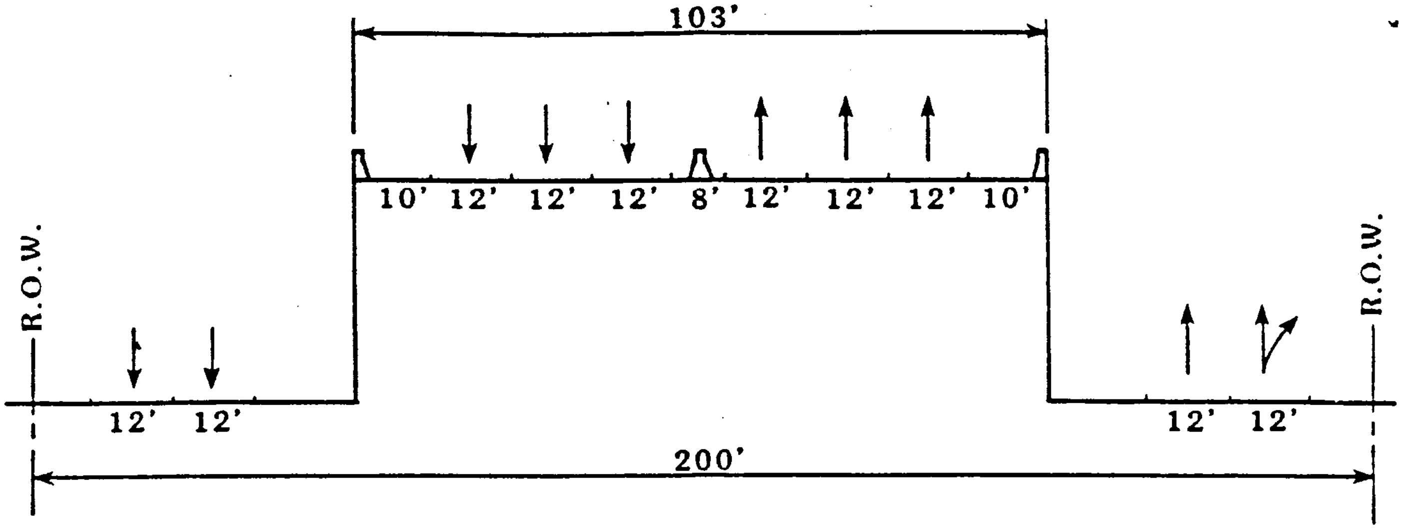


Figure 10. Case 3, US 183 at Balcones Woods Drive, Austin

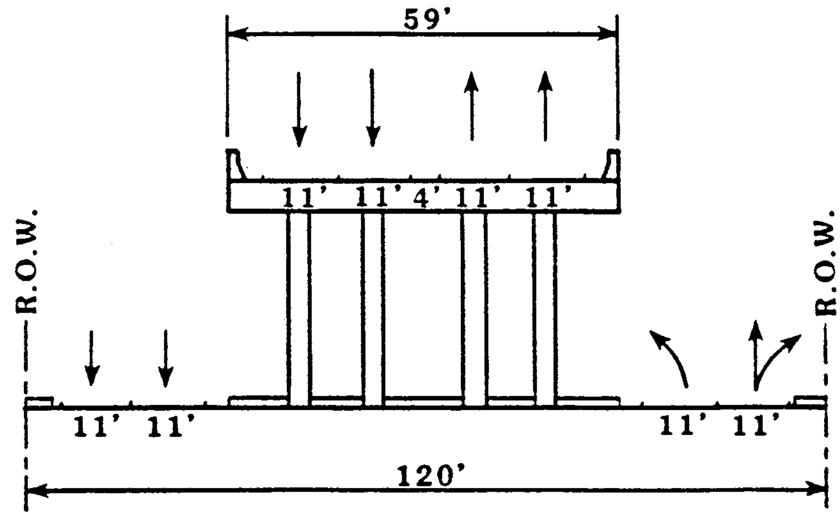


Figure 11. Case 4, Westheimer at Fondren, Houston

Traffic handling is expected to be laborious and expensive, unless the arterial is closed to traffic or extensive rerouting takes place. Access to adjacent properties does not seem critical due in part to the short length of the project and that at-grade access lanes would be on existing outside paved lanes.

Case 5 is an urban arterial flyover but with ample right-of-way that is 165 feet wide. The structure would be built half on columns and half on embankment to reduce pedestrian and property impacts. Four 12-foot lanes make up for a structure 60 feet wide. Figure 12 shows the cross section of this flyover looking east towards the intersection. A cross section looking west would show the westbound movement to consist of two left turning lanes, a through lane and a right turning lane. This particular case may be provided with a high type flyover (using 8+ foot right shoulders) to preserve the same safety clearances of the arterial, but the proposed design did not incorporate this concept due to the low speed limit (35 mph). This may be an unnecessary expense due to the stable traffic forecast and other roadway restrictions east and west of this location. The overall length of this structure is 1492 feet and the maximum grade is 5.5 percent at both approaches. Utility relocation is considered moderate. Traffic handling costs should be moderate even with the high cross street traffic since the ample right-of-way should permit detours through the job site.

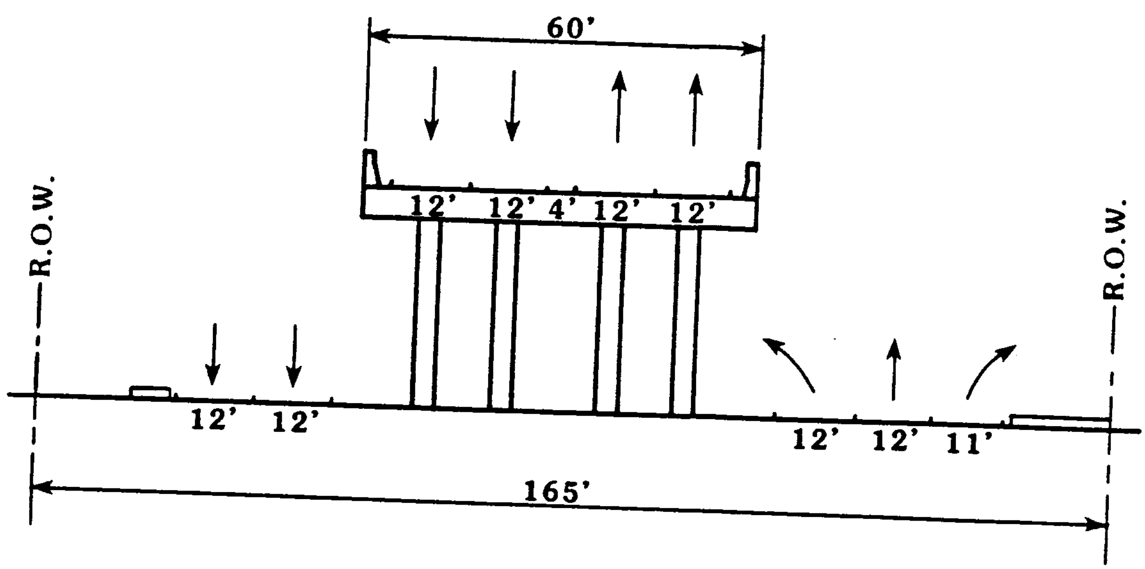


Figure 12. Case 5, NASA Rd. 1 at El Camino Real, Houston

Case 6 is a composite of three intersections each about 4000 feet apart, on the same arterial. This case is different in that right-of-way is only 100 feet wide and current demand can be satisfied with two-lane flyovers. Otherwise each is a typical arterial flyover bypassing another arterial. Half of each structure would be built on columns and the rest on embankments. The two 11-foot lanes make for a structure only 35 feet wide. Figure 13 shows the cross section of this concept looking west toward each intersection. Both approaches are symmetrical except for one location that incorporates a left turning lane under the structure. Overall length of the structure is 1492 feet, except for the one location that extends 230 feet to the west to provide the left turn lane. Maximum grade of the through lanes is 5.5 percent at both approaches. Utility relocation expenses are expected to be moderate (actual conditions unknown). Traffic handling costs should be moderate although some complications are possible due to the limited right-of-way and the high cross street volumes.

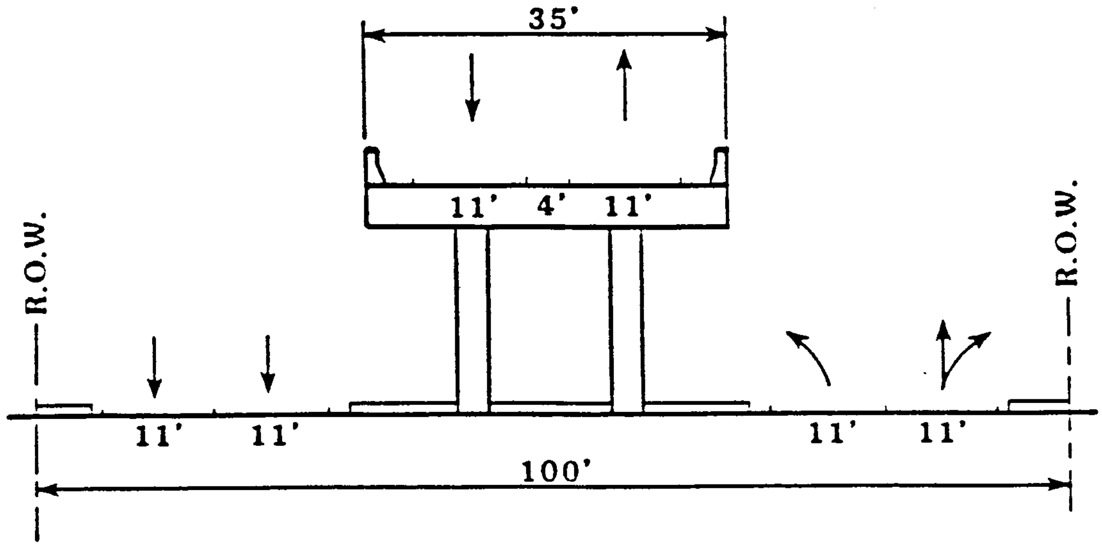


Figure 13. Case 6, Military Road at Commercial, Pleasanton and South Flores, San Antonio

Case 7 resembles Case 5 in having ample right-of-way (152 feet). In addition, it has extra right-of-way at the intersection that allows for wide separate right turns with pedestrian islands. The flyover would be half on columns and half on embankment. Four 12-foot lanes required a 60-foot wide structure. Here, a two-lane flyover would satisfy demand, but a four-lane minimum has been used in all cases, unless constrained by the right-of-way. Figure 14 shows the cross section looking east toward the intersection. Both approaches are close to symmetrical with the exception being the west approach that touches down at a point about three feet lower than the intersection, and this requires adding 50 feet in length. Thus, the overall length of the structure is approximately 1204 feet and the maximum grade on both approaches is 6.0 percent. Utility relocation is expected to be low in cost. The wide right-of-way should permit routing current traffic through the intersection and these costs should be low. Appendix B shows the at-grade treatment and other geometric considerations on this flyover.

At-Grade Treatments

A flyover is not the structure alone but a balanced treatment of an arterial intersection. Safe and smooth flow on the at-grade lanes is as important as that on the elevated through lanes. The at-grade transition dividing through traffic and turning traffic must be logical, simple and safe for motorists to accomplish. Geometric guidelines used in arterial design should be adhered to. When arterial lanes are dropped, advance warning of the upcoming flyover should be made. The at-grade intersection should be treated as a wide intersection rather than as a diamond interchange.

Ramp Approaches

Adequate tapering must be commensurate with the design speed along the arterial. When a median exists, be it as a barrier or for left turns, through lanes may need to be redirected to match the narrow or no-median of the flyover structure. A minimum taper of 10:1 can be used but a normal taper of 25:1 is desirable. The same criteria may be used to redirect lanes toward the at-grade intersection. Figure 15 shows this criteria for redirecting lanes.

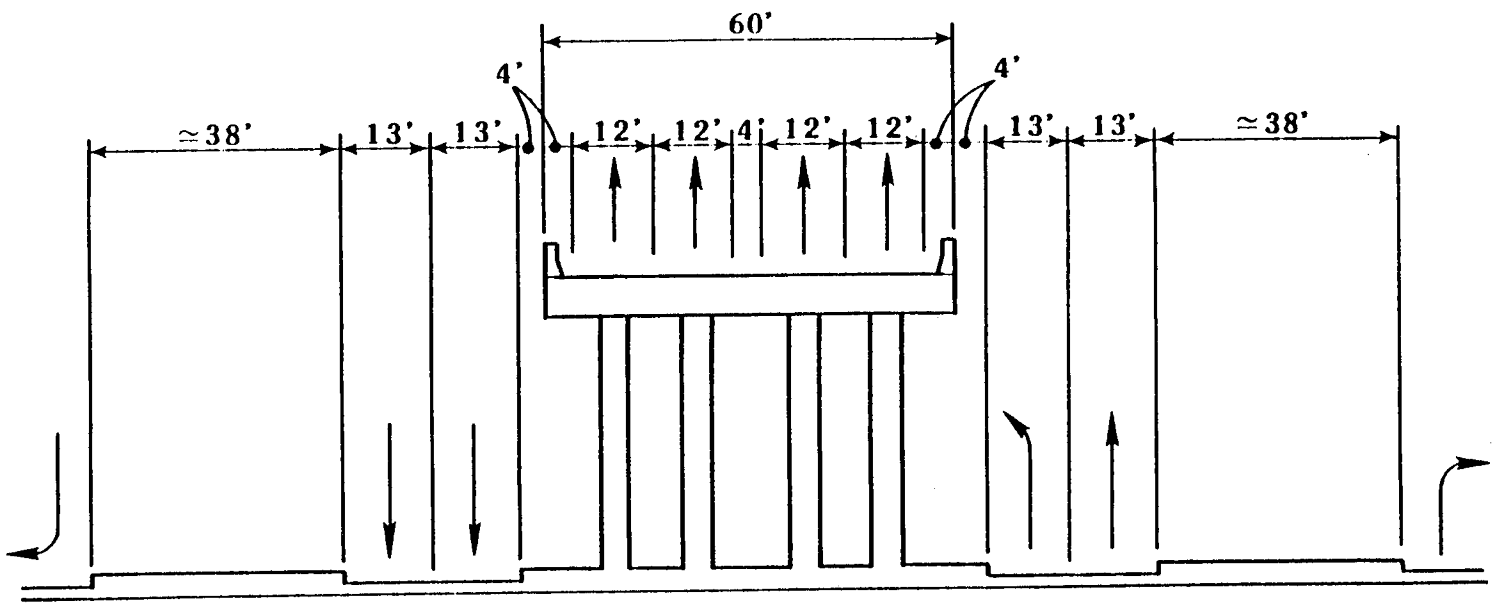


Figure 14. Case 7, University Drive at College Avenue, College Station

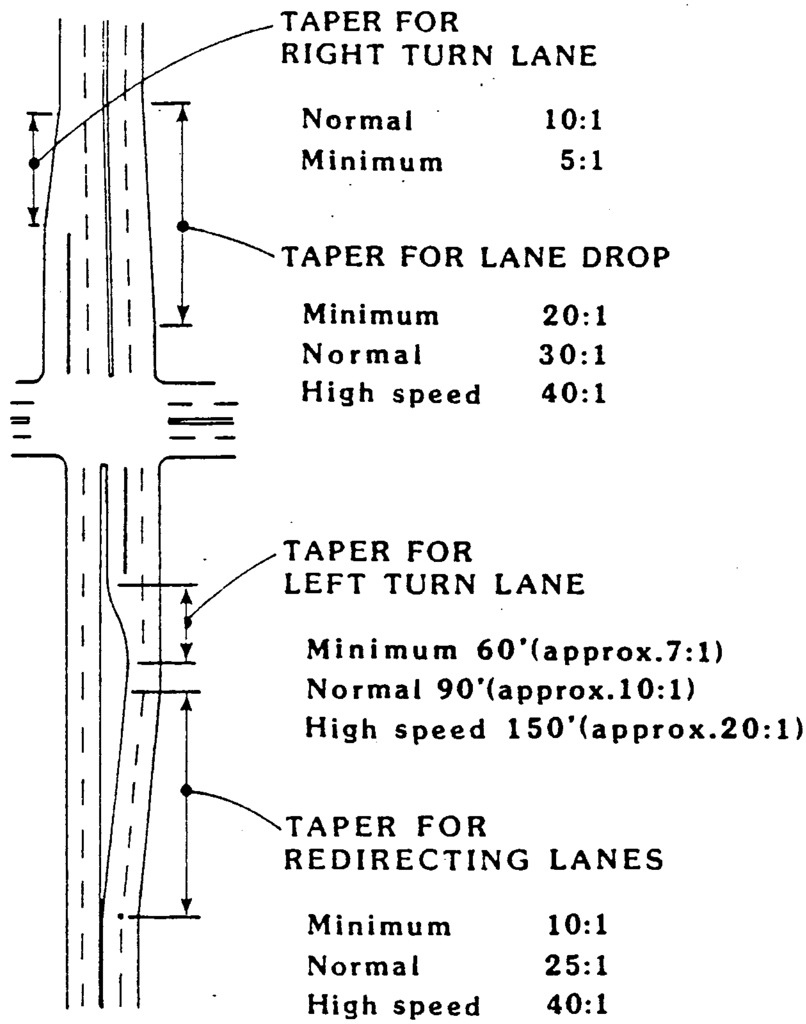


Figure 15. Taper Design for Urban Streets

Source: JHK & Associates, from Urban Transportation Operation Training - Design of Urban Streets Student Workbook, Federal Highway Administration, Washington, D.C.

Most arterial traffic going to the at-grade intersection will be turning into the cross-street. Tapering for left turns and right turns will be required unless these are a continuing approach lane to the at-grade intersection. A minimum taper of 5:1 can be used for the right turning lane and approximately 7:1 for the left turning lane. The latter would result in an S-curve about 60 feet long. At-grade vehicles turning from the cross street into the arterial may turn into a two-lane section that quickly drops one lane to merge with the arterial. Minimum taper should be 20:1. Figure 15 also depicts these minimums.

Single at-grade lanes on the arterial leading toward or from the intersection should be treated as turning roadways to determine the minimum pavement width. Since these are essentially straight segments the tangent criteria should control. A minimum paved lane width of 19 feet is recommended (face-of-curb to face-of-curb). Such width allows for passing of a stalled vehicle and considers enough single-unit trucks or buses to control design. Figure 10 shows minimum cross sections of at-grade intersection approaches using one and two lanes. Figure III-20 of the Green Book (AASHTO, 1984) expands on this criteria.

Barrier walls serving as flyover guardrails also need to be protected on the inbound side. Crash attenuators may satisfy this requirement. Slow speed arterials may forego this treatment by dropping the barrier (quickly sloping it) to the ground. Proper signs in advance of this transition point simplify the drivers' decision making process and reduce the risk of impact.

Intersection Geometrics

The number of lanes entering the intersection should allow most or all vehicles queuing at the intersection approaches to clear the intersection on each cycle. Of particular interest is the cross section of the cross street and the possible use of simultaneous left movements on the arterial.

A 100-foot clear span recommended for flyovers allows for up to eight 12-foot lanes on the cross street. These may be designated for through and turning lanes. A typical condition would be four 12-foot through lanes and one median-left-turn-lane.

Simultaneous left turns from the arterial are difficult, if not impossible, with a typical flyover. There are two ways of overcoming this difficulty. One is to provide left turn lanes under the structure as shown in Figure 3 for the Western-Belmont flyover in Chicago. However, this is expensive because of the special structural elements required, and because of the longer structure needed to reach minimum vertical clearance as the left turn lanes proceed under the structure prior to the intersection.

Another way of having simultaneous left turn movements from the arterial is by beginning to turn prior to the intersection, as shown in Figure 6. The modified structure and the extra clearance are somewhat more expensive than a conventionally retained structure, yet the time gained with simultaneous left turn movements may be the difference between a flowing intersection and a congested one. On the same hand, delay savings may surpass the extra expense of the modified structure and make it cost effective.

Similar treatments may be considered to allow simultaneous left turns from the cross streets. However, these may be more difficult because vehicles using a median left turn lane need to proceed straight before beginning to turn and the turning radius is tighter. Figure 6 shows the concept and the difference in radii required by left turn movements from the cross street and from the arterial.

Geometrics of the at-grade intersection should be carefully coordinated with the flyover design to satisfy traffic demand at an acceptable level of service. Flyovers are a capital intensive solution for intersections where no other at-grade improvements are satisfactory. Proper design of such improvement is required to justify the extra expense.

Benefits

Flyovers as grade separated lanes bypassing arterial intersections have been proposed to eliminate or reduce traffic congestion, particularly during peak hours. Reduced delay to motorists is the primary benefit followed by lower vehicle operating costs and accidents (Agent, 1975). Reduced air pollutant emissions also contribute to the benefits. Limiting driveway traffic to right turns only along the flyover may represent a disbenefit. Access elsewhere along the arterial usually is improved to varying degrees.

Estimate of Operating Conditions

A rather simple computer program was selected to analyze the selected intersections and to evaluate flyover operations. This program, PASSER II-84, has been developed by TTI and the SDHPT over a number of years. It is a deterministic (rather than probabilistic) model that maximizes signal progression bandwidth while minimizing overall vehicle delay (Chang, 1984). Although other models exist, this model was chosen because of its simple data requirements and because the before and after conditions could reasonably be assumed to be a simple four-way intersection. The analysis is intended for planning purposes. Obviously, more detailed analysis would be required for operational studies.

Table 6 presents a summary of the PASSER II-84 output that is used in the benefits assessment. This table uses the same case numbers as Table 5. Delay and stops per hour are given for peak and off-peak periods with and without a flyover. Base year is shown as 1985 and horizon year as 2005, a 20 year span commonly used for benefit cost analysis in highway projects. Also, the cycle length used by the program to calculate delay and stops is shown in Table 6. A cycle of 120 seconds usually indicates that one or more of the approach volumes exceeds capacity.

Delay Without The Flyover

Peak hour delay is important because delay increases exponentially as intersection demand approaches saturation flow. The peak period effect can be observed in Table 6. Off-peak hour delay is important because some intersections operate with congestion even during off-peak hours. Table 6 also shows the number of stops per hour occurring due to signal operation. Stops per hour are used to estimate fuel savings due to flyover operations.

Delay With the Flyover

Peak period delay is significantly reduced with the use of arterial flyovers. Cases 1 through 5 are estimated to gain over 50 percent reduction in 1985 peak period delay. Cases 6 and 7 show a lower level of improvement but still above 40 percent. All cases experience less than 50 vehicle-hours of delay during peak hours, and Cases 3, 5, 6 and 7 about 20 vehicle-hours of delay or less.

Table 6. Summary of Intersection Output from PASSER II

Case No.	Flyover (Yes or No)	Period & Year		Delay (Veh-hr/hr)	Stops[1] /hr	Cycle (sec)
1	No	Peak	1985	103.9	5,381	120
			2005	413.8	11,626[2]	120
		Off pk	1985	40.0	3,728	80
			2005	273.2	8,284[2]	120
	Yes	Peak	1985	43.2	2,603	115
			2005	138.6	4,815[2]	120
		Off pk	1985	20.4	1,984	60
			2005	78.8	2,993	120
2	No	Peak	1985	111.5	4,719	120
			2005	162.9	5,157	120
		Off pk	1985	24.0	2,608	60
			2005	65.5	3,642	120
	Yes	Peak	1985	49.3	2,886	120
			2005	31.6	2,693	90
		Off pk	1985	13.6	1,681	60
			2005	19.7	2,196	60
3	No	Peak	1985	108.2	5,771	120
			2005	346.3	11,614[2]	120
		Off pk	1985	26.5	3,323	70
			2005	123.2	6,897	120
	Yes	Peak	1985	21.1	1,256	70
			2005	34.9	1,980	120
		Off pk	1985	5.5	624	60
			2005	12.5	1,250	65
4	No	Peak	1985	100.7	6,080	120
			2005	323.4	10,405	120
		Off pk	1985	29.1	3,172	80
			2005	116.5	5,358	120
	Yes	Peak	1985	16.0	1,923	70
			2005	119.8	4,225	120
		Off pk	1985	12.3	1,490	60
			2005	61.5	2,855	120

Table 6. Summary of Intersection Output from PASSER II (continued)

Case No.	Flyover (Yes or No)	Period & Year		Delay (Veh-hr/hr)	Stops[1] /hr	Cycle (sec)
5	No	Peak	1985	60.6	3,665	120
			2005	101.1	4,606	120
		Off pk	1985	25.1	2,510	65
			2005	36.1	2,818	90
	Yes	Peak	1985	16.2	1,798	70
			2005	27.3	1,903	90
		Off pk	1985	8.4	1,122	60
			2005	15.6	1,647	65
6	No	Peak	1985	78.1	7,318	85
			2005	286.6	13,592	120
		Off pk	1985	34.3	4,684	60
			2005	78.0	7,490	80
	Yes	Peak	1985	41.8	4,724	60
			2005	143.8	7,806	120
		Off pk	1985	21.8	2,920	60
			2005	44.4	4,911	65
7	No	Peak	1985	29.0	2,862	80
			2005	107.1	4,483	120
		Off pk	1985	10.0	1,414	60
			2005	14.5	1,955	60
	Yes	Peak	1985	16.2	1,891	60
			2005	53.2	3,116	120
		Off pk	1985	6.9	945	60
			2005	12.1	1,567	60

[1]Stops/hr and vehicles/hr exclude right turning volumes when a separate right turning lane is present.

[2]Stops/hr limited to vehicles/hr since the PASSER II-84 output shows a higher number of stops than vehicles.

Annual Delay Savings

Total annual delay for current and future conditions can be estimated using the procedure outlined in Appendix E of the Highway Design Division Operations and Procedures Manual by the State Department of Highways and Public Transportation. An 18 hour day is assumed together with 253 work days per year. The following equation is used to calculate annual delay.

$$\text{Annual Delay} = D_p * H_p * 253 + D_o * ((18-H_p) * 365 + H_p * 112)) \qquad (2)$$

where: D_p, D_o = vehicle-hours of delay for peak and off-peak

H_p = number of peak hours experienced at each intersection per work day.

Total hours of delay savings for the current or the future year are calculated as follows.

$$\text{Current or Future Savings} = AD_{e,p} + AD_{e,o} - AD_{f,p} - AD_{f,o} \qquad (3)$$

where: AD = annual hours of delay for the existing configuration and for the flyover configuration, by peak and off-peak periods.

Annual savings are further assumed to grow linearly between the existing and the horizon year. Where congestion already exists this assumption should not be far off.

Table 7 shows the total hours of delay saved per year for each case. Annual delay savings go from 30,183 vehicle-hours for Case 7 during 1985 to 1,358,978 vehicle-hours for Case 1 during year 2005. Case 3 shows the greatest immediate benefit with over 200,000 vehicle-hours of delay saved during the first year of operation. Cases 1, 2, 3 and 5 all show delay reductions over 100,000 vehicle-hours during 1985. Cases 6 and 7 show much less improvement with less than 100,000 vehicle-hours of delay saved per intersection during their initial year of operation.

Future delay savings have a much wider spread. Case 1 shows over 1 million vehicle-hours saved during year 2005. This results from a very high projected traffic growth, as will be explained later, and results in an eight-fold increase in delay savings. Others follow, with Case 7 forecast to have only about 68,000 vehicle-hours of delay savings during year 2005.

Case 1 has the greatest average savings in delay during a 20 year design life. Cases 2, 3, 4, 5, 6 and 7 follow in descending order of average vehicle-hours of delay saved during the design life of each flyover.

Table 7. **First and Last Year Delay Savings**

Case No.	Year	Veh-Hours Saved	Veh-Hours Average
1	1985	170,368	
	2005	1,358,978	764,672
2	1985	107,644	
	2005	365,801	236,723
3	1985	204,863	
	2005	930,407	567,635
4	1985	187,832	
	2005	658,730	423,281
5	1985	137,751	
	2005	188,625	163,188
6	1985	100,189/3	
	2005	303,635/3	67,304
7	1985	30,183	
	2005	67,886	49,035

Accident Reduction

Flyovers have the potential to reduce intersection accidents. The reduced conflict points allowed to through traffic reduces the number of stops and maintains a more uniform traffic flow. The remaining at-grade traffic going through the intersection is exposed to fewer conflict points and fewer vehicles. The benefit of reduced accidents can be calculated by subtracting the number of accidents per year with the current intersection from the expected accidents with the flyover intersection.

Accident rates are difficult to estimate due to the very few documented cases. However, past experience provides some knowledge which can be applied to estimate the number of accidents spared. Analysis of the Ashland-Pershing flyover in Chicago, showed yearly accidents going down from 186 to 91, for a reduction of 51 percent (Walker, 1966). Another report by the Chicago Bureau of Street Traffic recorded a 39 percent decrease in accidents at the Archer-Ashland intersection in 1959. Walker also found that reduced accidents at flyover intersections did not bring about increased accidents at nearby intersections. The French have observed that prefabricated flyovers, which generally use marginal geometrics, have four times fewer accidents three months after opening to traffic (Le Franc, 1971).

Also, the severity of intersection accidents is reduced. An article comparing at-grade with grade separated interchanges (Agent, 1975) investigated the "correctable accidents", those that could be prevented with the use of grade separation. Agent found that 88 percent of 348 accidents that occurred at major intersections studied could be classified as correctable. More important, the principal type correctable was the right-angle collision, followed closely by the rear-end and the oblique or side swipe types. Right-angle collisions had the highest severity of any type of accident and were considered the most correctable.

Based on accident rate reduction and on the reduced severity of those, it is assumed that a flyover reduces the cost of accidents at an existing intersection by 50 percent. Future benefits or economic savings can be obtained assuming that accidents increase in proportion to the total intersection approach volume.

Current accidents for each intersection can be obtained from the Texas Department of Public Safety (DPS) accident files. Accidents occurring within the intersection proper and about .05 mile away from the intersection have been retrieved from DPS computer files. Table 8 presents the 1981-1984 accidents for each case. Intersection and intersection related accidents, as stored in the DPS files, have been combined.

Table 8. Accident Frequency of Case Studies

(Intersection and Intersection Related)

Case	1981	1982	1983	1984	Average
1	75	80	78	98	82.2
2	--	--	--	--	16.0 E
3	35	24	42	45	36.5
4	63	64	50	40	54.3
5	37	22	22	23	26.0
6a	11	15	8	16	
6b	15	16	23	21	14.8
6c	13	13	12	15	
7	2	3	2	0	1.8

The average intersection accidents per year range from 1.8 to 82.2. A 50 percent reduction would result in benefits ranging between 0.9 and 41.1 accidents saved per year with the flyover in place. Current economic benefits of any one of the above cases can be calculated multiplying the respective reduction in accident frequency by the average value of such an accident.

Economic Benefit Estimation

Flyover savings are calculated subtracting costs of the existing intersection from those of the intersection with the flyover built. Savings are accrued through reduced delay to vehicle drivers and passengers, through reduced fuel consumption of vehicles that do not stop or idle waiting for a signal light to change and, through benefits that result from the reduced frequency of accidents due to fewer vehicle conflicts through the at-grade intersection.

Assumptions

Road user cost savings due to delay are calculated for peak and off peak periods, for the current year and for the design year (20 years from current). Fuel costs due to stops and vehicle idling are similarly estimated. Fuel consumption rates developed by Winfrey (Winfrey, 1969) are used in the computations.

Accident costs are estimated based on the average yearly accidents at a particular intersection. It is assumed that the existence of a flyover would reduce accidents by 50 percent as previously discussed.

All operational costs are annualized based on an 18 hour day and 253 work days per year, as outlined in the Highway Design Division, Operations and Procedures Manual (SDHPT, 1981). The Appendix A spreadsheet program is used in these computations. Below, Table 9 shows parameters assumed to compute delay costs. Fuel cost was taken as $1.20 per gallon. These are based on 1985 conditions and may be adjusted as deemed necessary for future use.

Table 9. Assumptions on Cost of Delay and Vehicle Occupancy

Mode	1985 Dollars/ Occupant-Hr.	Occupants/ Peak Hour	Occupants/ Off-Peak Hr.
Auto	7.50	1.3	1.8
Truck	20.15	1.0	1.0
TracTlr	20.15	1.0	1.0
Bus	7.50	16.0	5.0

Table 10. Total Annual Cost

(1985 million dollars)

Case	Flyover	User			
No	(Yes or No)	Year	and Fuel	Accidents	Total
1	No	1985	5.344	0.612	5.956
		2004	29.520	1.132	30.652
	Yes	1985	2.617	0.306	2.923
		2004	8.882	0.566	9.448
2	No	1985	3.384	0.088	3.472
		2004	7.527	0.120	7.647
	Yes	1985	1.812	0.044	1.856
		2004	2.219	0.060	2.279
3	No	1985	4.153	0.270	4.423
		2004	15.715	0.495	16.210
	Yes	1985	0.838	0.135	0.973
		2004	1.700	0.247	1.947
4	No	1985	4.260	0.402	4.662
		2004	15.042	0.596	15.638
	Yes	1985	1.365	0.201	1.565
		2004	7.087	0.298	7.385
5	No	1985	3.038	0.192	3.230
		2004	4.434	0.218	4.652
	Yes	1985	1.009	0.096	1.105
		2004	1.774	0.109	1.883
6	No	1985	4.281	0.245	4.526
		2004	10.347	0.387	10.735
	Yes	1985	2.644	0.122	2.766
		2004	5.784	0.194	5.978
7	No	1985	1.316	0.013	1.329
		2004	2.719	0.018	2.737
	Yes	1985	0.857	0.006	0.863
		2004	1.804	0.009	1.813

The occupant delay costs for each mode were taken from The Value of Travel Time: New Estimates Developed Using a Speed Choice Model (Chui, 1985). Auto occupants and bus drivers and occupants are considered to have a value of $7.50 per hour of delay, while truck drivers' value of time is taken as $20.15. A different level of vehicle occupancy is assumed for peak and off peak-period usage of autos and buses.

Accident costs are estimated to average $7,400 for urban sites on divided highways and $5,500 for urban sites on undivided roadways. These values represent all direct and indirect costs associated with the accident, as defined in Cost of Motor Vehicle Accidents in Texas, (Rollins, 1985). Values apply to multi-vehicle intersection accidents and include angle, head-on, rear-end and other type accidents.

Flyover Savings

Table 10 provides a summary of costs for each case with and without a flyover, for years 1985 and 2004. Total savings accrued during the first and last year of the study period are the sum of delay savings, vehicle fuel savings and accident savings, expressed in dollars. Table 11 shows savings for 1986 and 2005 for each case studied. These vary from $0.465 million for Case 7 to $3.45 million for Case 3 in 1986, and from $0.924 million to $21.2 million for year 2005.

Table 11: First and Last Year Total Savings

(1985 million dollars)

Case	1986	2005
1	3.032	21.200
2	1.616	5.367
3	3.450	14.260
4	3.096	8.253
5	2.124	2.770
6	1.760	4.757
7	0.465	0.924

Table 12 shows the present worth of savings accrued over a 20 year period at three different discount rates. Using the more conservative of the rates, 8 percent, Case 1 shows a present worth of approximately $96 million followed by Case 3 at $73 million, Case 4 at $49 million, Case 2 at $29 million, Case 6 at $28 million, Case 5 at $23 million and Case 7 at $6 million. Their relative rank is shown in Table 12.

Table 12. Present Worth of Savings

(1985 million dollars)

Case	Discount Rate			Rank
	4%	6%	8%	
1	147.90	118.20	95.85	1
2	43.99	35.76	29.51	4
3	110.40	89.21	73.19	2
4	72.36	59.19	49.15	3
5	32.66	27.33	23.20	6
6	41.51	33.94	28.17	5
7	9.01	7.44	6.23	7

As explained earlier, all these projects have different geometric and operating characteristics and some which are more difficult to build due to existing utilities, traffic handling during construction and dimensions of the flyover proper. Some will be more expensive than others. Once total cost is estimated, the relative merit of each project can be established based on a benefit to cost ratio.

Construction Cost Estimation

Cost estimates have been prepared for the seven cases studied. The actual construction costs vary from one district to another since bids are dependent on prevailing economic conditions, etc. The estimates prepared for this research have been based mostly on the 1984 Dodge Guide to Public Works and Heavy Construction Costs (McMahon, 1983), on one single "plans estimate" for the construction of a flyover FM 149 over FM 1960 in Houston and on the SDHPT Bridge Division Statistical Report for 1984.

Conventional Flyovers

Table 13 presents a summary of the estimated construction costs of conventional flyover projects. These have been divided into five different categories: structure, at-grade roadway improvements, signals-signs-markings-illumination, utilities, and traffic handling. The structure is the flyover proper and includes the intersection bridge, retained and/or viaduct type ramps, barrier walls and portland cement concrete running surfaces. The at-grade improvements to the intersection, utilities and traffic handling follow in overall costs, as these vary significantly from project to project.

Table 13. Conventional Flyover Construction Costs

(1985 million dollars)

Case	Structure	At-grade	Signal, Signs Markings, Illum.	Utilities	Traffic Handling	Total[a] (Sum * 1.2)
1	2.645	0.354	0.187	0.800	0.200	5.023
2	2.120	0.286	0.133	0.400	0.200	3.767
3	2.652	0.395	0.203	0.400	0.100	4.499
4[a]	1.466	0.050	0.107	0.800	0.400	3.388
5	1.927	0.273	0.148	0.200	0.100	3.178
6a	1.619	0.050	0.141	0.200	0.100	
b	1.376	0.050	0.118	0.200	0.100	6.956
c	1.375	0.050	0.118	0.200	0.100	
7	1.555	0.115	0.101	0.100	0.050	2.305

[a]The 1.2 multiplier is composed of a 9% for mobilization and a 10% for engineering and contingencies, each added sequentially on the subtotal.

The indirect cost of construction delay and diversion of motorists should be considered. Actual costs will vary depending on traffic control measures and many variables influence these. In the absence of a detailed control plan for each site it was assumed that motorists and vehicle operating costs increase by 25 percent during construction since lanes are closed and/or geometric standards reduced. As previously explained, a flyover project should take about 18 to 24 months and a prefabricated about 5 to 6 months. These costs are estimated as shown in Table 14.

Table 14. Indirect Construction Costs[1]

(1985 Million dollars)

Case	Conventional	Prefabricated
1	2.672	NA
2	1.692	0.423
3	2.077	0.519
4	2.278	0.570
5	1.519	0.380
6	2.141	0.535
7	0.658	0.165

[1]Conventional estimated as 25% times 2 years or equal to 1/2 of the first year operating costs. Prefabricated estimated as 25% times half a year or 1/8th of the first year operating costs.

Prefabricated Flyovers

Prefabricated flyover cost estimates have been calculated for the same categories as the conventional. A few assumptions differ. The retained ramps are each only 200 feet long and the remaining length is the prefabricated structure. Minimal utility relocation takes place, mostly to adjust drainage. Construction takes only 6 months rather than 2 years. Traffic handling and congestion costs are considerably reduced during construction.

Table 15 presents the direct construction cost estimates for the prefabricated flyovers. A brief comparison between Tables 13 and 15 shows that drastic increases result in the structure costs. Utility relocation and traffic handling costs decline based on the assumption for this method of construction.

Table 15. Prefabricated Flyover Construction Costs

(1985 Million dollars)

Case	Structure	At-grade	Signals, Signs Markings, Illum.	Utilities	Traffic Handling	Total (Sum * 1.2)
1		Not Applicable				
2	5.397	0.286	0.129	0.100	0.100	7.215
3	13.005	0.395	0.177	0.100	0.050	16.472
4	2.485	0.050	0.104	0.100	0.100	4.608
5	5.020	0.073	0.144	0.050	0.050	6.645
6a	3.567	0.050	0.141	0.050	0.050	12.438
b	2.980	0.050	0.124	0.050	0.050	
c	2.980	0.050	0.124	0.050	0.050	
7	3.540	0.115	0.108	0.025	0.025	4.575

Benefit to Cost Ratio

The benefit to cost ratios of the conventional cases studied vary from 2.1 to 12.5 as listed in Table 16. Prefabricated flyovers show a very different ranking. However, prefabricated flyovers do not appear to make any projects more attractive than using conventional construction.

Table 16. Benefit to Cost Ratio

(20 Year Life)

Case	Conventional	Rank	Prefabricated	Rank
1	12.5	1	NA	--
2	5.4	4	3.9	3
3	11.1	2	4.3	2
4	9.6	3	10.6	1
5	4.9	5	3.3	4
6	3.1	6	2.2	5
7	2.1	7	1.3	6

Another way of looking at flyover cost effectiveness is based on the immediate rate of return or first year benefits divided by construction costs. Such an approach is used with prefabricated flyovers (Byington, 1981) and is particularly useful for comparing projects with a short lifetime. An immediate rate of return of 20 to 120 percent has been estimated for urban flyovers (LeFranc, 1971) built in France.

Table 17 shows the immediate rate of return for conventional and prefabricated flyovers, even though the primary application of this concept is for the latter. Conventional flyover immediate rates of return vary between 0.16 and 0.53. It would take at least another year for the better cases to break even.

Table 17. Immediate Rate of Return

(First Year Life)

Case	Conventional	Rank	Prefabricated	Rank
1	0.39	4	NA	--
2	0.30	5	0.21	3
3	0.52	2	0.20	4
4	0.53	1	0.58	1
5	0.45	3	0.30	2
6	0.19	6	0.14	5
7	0.16	7	0.10	6

Only one of the prefabricated flyovers shows an immediate rate of return above 0.5 and that is Case 4 with a 0.58. Benefits would match costs in about 2 years. Thus, if other improvements requiring demolition are planned for the near future this structure still could be justified on a temporary basis. All others take longer for the benefits to match costs since their ratios vary between 0.01 and 0.30.

Access Impacts

Various other issues need to be considered regarding the use of a flyover. In general, it can be stated that the installation of a flyover would initially bring improved traffic flow along the arterial. However, this condition can induce traffic using other arterials to switch to the improved facility and thereby to create as much congestion as before. The same could be said about noise and air pollutants. However, these problems may never be experienced if adjacent intersections have a lower traffic handling capacity along the arterial than the flyover.

The effects of a flyover on property access and local vehicle circulation can be major. These effects are not necessarily independent of the operational impacts, but for analysis purpose they can be considered separate. For example, flyovers create a physical barrier that prohibits left turns to and from the arterial over a distance exceeding 900 feet from the cross street in each direction.

Access impacts are influenced, if not determined by the:

- number of driveways along the arterial within the influence of the flyover,
- existence of a cross street within the range of influence by the flyover,
- time of day and intensity of traffic using driveways and cross streets,
- optional access to the affected parcels, and
- existing left turn signs or restrictions such as raised or grass medians.

The case study access impacts are outlined in Table 18. Overall, it can be stated that access to properties along the arterial in proximity to a congested intersection may be negatively affected but should not be a deterrent to build a flyover. Specific cases such as small businesses and fast food places may warrant special attention to find out options to mitigate or improve access to them.

General Observations

Seven case studies have been evaluated. However, the objective of this study is not to come out with specific project recommendations but to analyze

Table 18. Flyover Impacts on Access

Case	Ext'g Median or L.T. Barrier	Cross Street Affected	Impacted Parcels						Comments
			Commercial	Alt. Access	Office	Alt. Acc.	Residential	Alt. Acc.	
1	West-810'	West-alley	Lumber yard	No	--		--		Limited impact,
	East-800'		industrial	Yes					except lumberyard
2	None	North - 2	6	No	--		--		Major impact to 6
			11	Yes					parcels w/no alt-
									ernative access
3	Over 1200'	None	--		--		--		No impact
	North & South								
4	West-470'	East-1	1-rear alley	Yes	1	No			Moderate impact to
	East-440'								cross street traffic
5	East-1070'	West-1	1	Yes	--		--		Median access to
	West- 350'								Burger King would
									need to be closed.
6 a	None		17E	No	--		--		Considerable impact to
			14E	Yes	--		--		small businesses.
b	None		7E	No	--		--		
			14E	Yes	--		--		Alternate access available
c	None		10E	Yes	--		--		No major impact
7	West-500'	West-1	2	Yes	--		Apartments	Yes	No major impact

SIMPLE PROCEDURE TO EVALUATE PROSPECTIVE FLYOVERS

The preceeding case studies demonstrate the feasibility of using flyovers to solve arterial intersection capacity problems that cannot be resolved with conventional at-grade treatments.

The following relationships may be used to screen potential intersections in order to select those that would be most cost effective.

Benefits

Throughout the study a relationship between benefits and ADT was perceived. Of particular interest is the first and last year savings, because they followed about the same pattern as the total approach daily volumes for the respective years. Since ADT is a commonly available statistic for most arterials, and traffic projections are commonly based on ADT, the relationship between ADT and benefits was investigated.

Both first and design year approach daily volumes are available and average approach volume for the 20 year period can be calculated. Table 19 shows these volumes. Case 6 volumes have been divided by three to represent the average intersection served. In the same table present worth of benefits is included, expressed in 1985 million dollars. A brief examination of the ranks assigned to the average approach volume and to the present worth shows the similarity between the two.

The apparent relationship was tested for linearity. The correlation coefficient "r" was found to be 0.99 indicating a strong linear relationship significant at the 0.01 level. The resulting equation is:

$$EPW = -39.2 + 0.914\ V \qquad (9)$$

where, EPW is present worth in $millions, and
V is the average daily approach volume in thousands, calculated as ((current + 20th Year)/2.).

Table 19: Approach Volumes and Present Worth of Benefits

Case	Approach Volume Average (thousands)	Rank	Present Worth 1985 ($ millions)	Rank
1	148.178	1	95.85	1
2	66.378	5	29.51	4
3	122.450	2	73.19	2
4	99.705	3	49.15	3
5	66.875	4	23.20	5
6[1]	55.708	6	9.39	6
7	55.066	7	6.23	7

[1]Data is average for each of three intersections represented by this case.

However, since this equation is based on several assumptions including existing congestion, and because of the few observations, it should be used with caution and only within the range of 50 to 150 thousand vehicles per day. In the absence of more detailed data, the above equation may be used to estimate the present worth of a flyover and for the preliminary screening of intersections where congestion is known to exist.

Costs

Several factors affect construction costs such as geographic location, status of the economy, materials used, etc. Yet, some generalizations can be made to provide a planning estimate based on the type of structure considered.

In general, direct flyover costs can be broken down into five general areas. These are: 1) the structure, 2) at-grade improvements, 3) the intersection signal, signs, and illumination, 4) utility relocation and improvements and 5) traffic handling during construction. In addition, a percent is added for mobilization and another percent for engineering and contingencies; this can be represented as a multiplier of "1.2", currently used by the SDHPT.

The structure is the most expensive and the more time consuming to estimate. However, some general assumptions can be made based on current estimates by the SDHPT for similar structures of the conventional type, to approximate average costs for the various types of flyovers. Further, typical characteristics of a flyover can be assumed such as design speed and a flat grade along the whole length of the structure. The conventional type structure would be half on columns and half on embankment. The prefabricated structure would use 200-foot embanked ramps at each end with the remainder being on columns. A minimum vehicle clearance of 16.5 feet would be kept over the crossing arterial along a clear span of 100 feet. Table 20 shows geometric assumptions of the "representative" flyover.

Table 20. Typical Flyover Characteristics Influencing Costs

	Low Type	High Type
Design Speed	35 mph	60 mph
Total Length	1154'	2087'
Structure Width	varies by lanes	varies by lanes
Clear Span (16.5' V.C.)	100'	100'
At-grade improvements	resurface	use border
Signal	modify ext'g	modify ext'g
Signs & Markings	as required	as required
Illumination	on flyover only	on flyover only
Utilities	moderate	high
Construction Traffic Handling	moderate	high

Other factors affecting costs have been included in the above table. At-grade improvements include resurfacing at-grade access and approaches on the cross street, as required, together with driveway and curb adjustments. Signal works assume the use of an existing controller with new loops and other required modifications. Signs and markings include removal of old, useless ones and installation of new ones, as required. Additional illumination would be provided on the flyover only, and existing intersection illumination would remain as is. Utility relocation is required for the conventional but only structure drainage is required with the prefabricated. Table 21 gives the estimated construction cost of the flyovers by number of lanes, type, and construction method.

The prefabricated structure uses the same assumptions as the conventional method except that only the first 200 feet of each approach are on retained embankment, utilities are estimated at one-fourth of the conventional and traffic handling at one-half of the conventional.

Cost of the conventional structures ranges from a low of $1.6 million to $6.2 million, while the prefabricated ranges from $2.8 million to $10.8 million. The prefabricated structure is between 50 percent and 125 percent more capital intensive than the conventional. However, there may be many applications for either construction method depending on site characteristics and the project objectives.

Table 21. Direct Construction Costs of Typical Flyovers
(1985 million dollars)

Construction	Type[1]	Lanes 2	Lanes 4	Lanes 6
Conventional	Low	1.62	2.17	2.72
	High	4.19	5.19	6.20
Prefabricated	Low	2.85	4.49	6.13
	High	6.23	8.49	10.75

[1]Low means designed for 35 mph and with limited right shoulders; high means designed for 60 mph and with full right shoulders and an 8-foot median provided with CMB.

Indirect flyover costs due to construction delay and diversion must be considered. Table 15 presents estimates prepared for the various cases studied. In the absence of better data a $2.0 million amount is suggested for planning purposes.

Suggested Warrants

A set of warrants to justify development of a flyover has been proposed. If the conditions of these warrants are met, a flyover is justified based on function and economics.

1. The intersection is a bottleneck on an arterial and conventional traffic engineering measures such as prohibiting turning movements cannot resolve the capacity problem.
2. A minimum of four arterial through lanes already exist and maximum use of the intersection right-of-way has been made. The sum of critical lane volumes approaches or exceeds 1200 vph.
3. It is very expensive and/or contrary to the arterial objectives to obtain additional right-of-way.
4. Impact on access to adjacent properties and minor streets limited to right turn only movements is not severe. No traffic crossing the arterial should be allowed closer than 200 feet from the flyover's touchdowns.
5. The accident rate (accidents per vehicle entering the intersection) is significantly higher than rates on nearby intersections of the same arterial and conventional traffic engineering measures cannot resolve this problem.
6. Benefit to cost ratio is greater than three based on the method incorporated in this report or as approved by the SDHPT. Ratios above one may be justified but a detailed analysis should be conducted to include all benefits and costs.

Screening Method

A screening method to investigate a congested intersection as a potential site for a flyover treatment is presented below. As an example, the intersection of Burnet Road and Anderson Lane in Austin will be used.

- It has been reported that severe congestion exists at this critical intersection, that the intersection is a bottleneck on Burnet and that at-grade measures cannot resolve the capacity problem. Small businesses are located on the west side along Burnet and access to major shopping malls and other small businesses exists on the east side.

- The responsible staff visits the site, confirms the above, sketches general intersection geometrics and records observed traffic conditions including the signal timing.

- Aerial photos, design drawings, current and future ADTs are procured from existing sources. Traffic accidents and vehicle counts by lane are also obtained, if readily available. The right-of-way available is determined from design drawings.

- Benefits are estimated by obtaining the average daily traffic approaching the intersection (or by the sum of two-way ADT on all approaches divided by two) for the current and future year, averaging that approach volume and using the estimated present worth equation.

$$\text{Average Approach Volume} = \text{1985 Volume} + \text{2005 Volume}$$

$$\text{AAV} = 65{,}217 + 67{,}538$$

$$= 66{,}378$$

then,

$$\text{EPW} = -39.2 + 0.914\ V$$

(EPW in \$ millions and V in thousands)

$$= -39.2 + 0.914\ (66.378)$$

$$= 21.5 \text{ million dollars}$$

This value is similiar to the one obtained through a detailed analysis.

- Construction costs are estimated using the typical case for conventional construction low type and using 4 lanes (see Table 21). That is, \$2.17 million. The construction plans and traffic data indicate that utilities and traffic handling will likely be more expensive than the typical case which considers both of these factors as moderate. Indirect construction costs are estimated at $2.0 million.

- A benefit to cost ratio would show:

$$\begin{aligned} B/C &= EPW/Cost \\ &= 21.5/(2.17 + 2.0) \\ &= 5.2 \end{aligned}$$

and this is reasonably close to the 5.4 B/C ratio obtained through the detailed method.

- Land use up to 1000 feet away from the intersection is investigated for possible impacts. In this particular example some significant impact may be induced on the small businesses located along the east side of the arterial.

- Accident rates would be investigated as part of the detailed analysis since this is not a major concern at this particular intersection. However, benefits already incorporate reduced accident rates in the dollar estimate.

Detailed Method

A more detailed analysis of a proposed flyover includes: data collection, concept design, evaluation of operating conditions, benefits estimation, adjustment of concept design, cost estimation, benefit/cost analysis, and impact assessment. Figure 16 shows a flow chart of these major areas of activities and the relationship to each other.

Data collection includes site visits by a person participating in the final assessment of the potential flyover. Detailed geometrics should be obtained from the most recent design plans, together with utilities, dedicated right-of-way and other aspects of the intersection that may affect the flyover. Aerial photos extending up to 1500 feet away from the intersection in each direction along the arterial would provide a static view of the

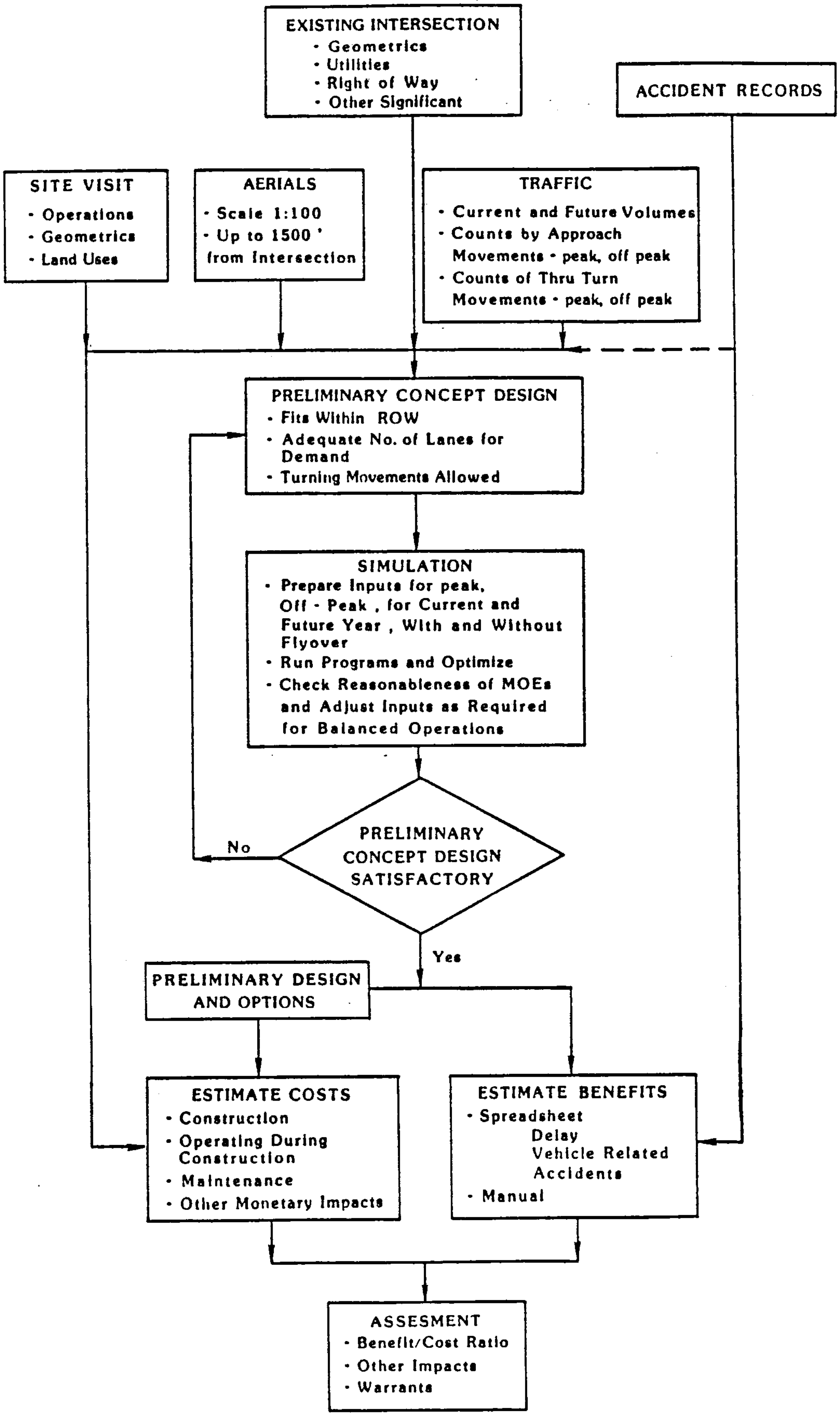


Figure 16. Flowchart For Detailed Method of Assessment

intersection operation, adjacent land uses and overall geometrics. Current and future approach volumes are obtained from agency records. Counts of all turning and through movements are obtained from available sources or by field crews as part of the assessment effort. These include a separate count of vehicles travelling on the arterial that turn left approximately 1000 feet prior to the intersection or that turn left or right 1000 feet after crossing the intersection. Accident records are obtained from the agency in charge, preferably, for a period of four years.

With the above information a preliminary concept design of a flyover can be prepared. At-grade approach lanes are provided to allow all required turning movements. Minor at-grade improvements which can help existing traffic flow, including optimum signal operation, are considered to be in place.

Traffic volume by lane group, by peak and off-peak period, for the current and design year are input to PASSER II. Data on turning lane capacity, minimum green for each phase and permissible phase sequence also is provided. If other signalized intersections exist within a half mile or less along the arterial, these should be included as part of a coordinated signal system. The first run is made with an arbitrary cycle length and subsequent runs made to optimize the cycle length and reduce delay. The measures of effectiveness (MOEs) provided by the output are used to detect any improper condition such as a particular movement operating beyond capacity; if necessary the capacity, the minimum green or other inputs are adjusted to obtain a desirable balance.

If critical changes are required such as to provide an extra turning lane to add capacity, the preliminary concept design is revised and the PASSER II run again, as required. A preliminary design with cross sections and plan view are prepared once the concept design is acceptable.

Costs are estimated for the flyover concept. The options to be considered may include a conventional and a prefabricated structure. Extra operating costs due to delay and vehicle usage are roughly estimated considering the construction time and local characteristics. Other monetary impacts such as paying for property to be acquired are included, if appropriate. Maintenance costs should be included, if substantial, as may be the case for prefabricated structures.

Benefits are estimated based on reduced hours of motorist delay, fuel consumed and accidents. Outputs from the PASSER II program are used to estimate present worth of benefits using the spreadsheet microcomputer program in Appendix A. Also, present worth can be calculated using the manual procedure presented in Appendix D.

The overall assessment of a flyover project is based on a favorable benefit-cost ratio, other impacts and meeting most or all of the warrants. Since the warrants are not based on precise values, judgement on the part of the assessment team should prevail.

FINDINGS AND CONCLUSION

The use of arterial flyovers in the United States has been very limited and little documentation exists on the benefits and costs of these structures. Although they resemble a freeway interchange, they are intended to use arterial right-of-ways. The limited lateral clearances used on flyovers allow these to fit where interchanges cannot be built and extra lanes cannot be provided.

A minimum right-of-way needs to be available to maintain minimum safety standards on the grade separated structure and optimum traffic flow along the at-grade approaches to the intersection. Recommended right-of-way minimums for the typical flyover (low type) are: 100 feet for a two-lane structure, 120 feet for a four-lane structure and 140 feet for a six-lane structure. Additional right-of-way is required for the high type flyover to provide full right shoulders. A narrower right-of-way has been used in the past to build some flyovers but they are not recommended as a permanent improvement.

Flyovers increase the intersection capacity by diverting arterial through-vehicles over cross street traffic and other turning vehicles. Capacity per lane of a typical flyover (low type) is estimated at 1800 vehicles per lane per hour. High-grade flyover capacity is about 2000 vehicles per hour per lane or that of a freeway lane.

Nine potential flyover sites in Texas were investigated to analyze current and future conditions with and without a flyover. Arterial through-traffic using the grade separation was assumed to incur no delay. Operations at-grade are those of a signalized four-way intersection. Capacity per lane is about 1750 vehicles per hour of green, but lost time due to the traffic signal, turning volumes, number of lanes per approach, etc. affect total intersection capacity. Therefore, analysis of a given set of conditions was done using PASSER II-84, a simple computer program. Outputs of this program provided adequate measures of effectiveness, including delay, to analyze intersection operations and to estimate direct economic benefits of a fly-over.

Benefits derived from a flyover depend to a great extent on the assumptions used to estimate savings of motorist time, vehicle usage and accident reduction. Using current assumptions used by SDHPT to evaluate highway projects in Texas, a method can be devised to estimate project benefits based on the present worth of savings. Seven cases comprising nine independent intersections were studied.

A strong relationship was found between benefits of a flyover and the average approach volume at a congested arterial intersection. The average approach volume is the sum of all current daily traffic approaching an intersection plus the 20 year projection of daily traffic approaching the same intersection, divided by two. A rule of thumb derived from that relationship suggests that a congested intersection with an average approach volume of 50,000 vehicles per day may justify a simple arterial flyover, based on a benefit-cost ratio exceeding one. At that level benefits add to about $6.5 million. A simple conventional flyover is estimated at about $5.0 million, including delay and diversion during construction.

No useful relationship was found between benefits and the arterial left turn volumes. However, excessive delay may be observed once left turn volumes exceed 200 vehicles per hour per lane and two turning lanes may be required. Also, no useful relationship was detected between benefits and the arterial traffic to cross street traffic ratio.

Two major methods of flyover construction have been identified and their advantages and drawbacks discussed. These are: 1) the conventional, cast in place structure, and 2) the prefabricated, fast-to-erect structure. The conventional flyover is generally cheaper, but construction takes from 18 to 24 months and the impact on adjacent property during construction may be severe. The prefabricated flyover is generally more expensive but the potential impact to adjacent property is lower with construction taking between 4 and 6 months. Delay and diversion of traffic during construction is related to specific construction measures required. Maintenance costs for the prefabricated flyover may be higher than for the conventional flyover but the magnitude is not known. In general, the conventional flyover appears less expensive.

A set of warrants has been proposed to justify construction of a flyover. Each is measurable, but assessment requires judgement because they are based on relative rather than absolute values. Warrants can be used during the screening of a project and should remain valid through final design.

In general, it is concluded that flyovers can be a cost-effective option to increase the capacity of congested arterial intersections when other less capital intensive, at-grade solutions have been exhausted. Assuming at-grade options are not available the benefit to cost ratio of building a flyover at each of nine arterial intersections studied in Texas has been found to vary from 1.3 to 12.5 depending on traffic conditions, site geometrics and method of construction among other factors. Those with the highest benefit to cost ratios and where other at-grade options are negligible on non-existent have the greatest potential. These generally correspond to intersections with very high existing traffic and a high steady growth in traffic demand.

The use of consecutive or multiple flyovers along congested arterials appears just as cost effective but with the potential to improve traffic flow along the whole length of a congested arterial. The analysis methods presented here can be used to assess such improvements but the issue has not been directly addressed.

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APPENDIX A

Spreadsheet Program to Compute Flyover Savings

```
SuperCalc ver.  1.00
RESEARCH
A1        = "RESEARCH
A4        = "COST OF ALTERNATE INTERSECTION TREATMENTS
A6        = "EXISTING RESEARCH BLVD.(US-183) AT BURNET RD.
A7        = '
C7        = "Delay
D7        = "   Stops
E7        = " Idling
F7        = "  Stops
G7        = "  Pass
H7        = "TOT COST
I7        = " ANNUAL
K7 TR     = "ANNUAL
L7        = " VEHICLES
M7        = " VEHICLES
N7        = " ACCIDNTS
O7        = " ACC COST
A8        = "Time
B8        = "Year
C8        = "(hrs)
D8        = "      /hr
E8        = "   Cost
F8        = "   Cost
G8        = "   Cost
H8        = "/hr
I8        = " COST
K8 TR     = "DELAY
L8        = "    /HOUR
M8        = "    /YEAR
N8        = "    /YEAR
O8        = "    /YEAR
A9        = "----
B9        = "
A11       = "Peak
B11       = "1985
C11       = 103.9
D11       = 5381
E11 $     = C11*E40*E41
F11 $     = D11*F47*E41
G11 $     = C11*I48
H11       = SUM(E11:G11)
I11 I     = H11*K43*253
K11 I     = C11*K43*253
L11       = 6370
M11       = L11*K43*253
N11       = M43
O11       = N11*N43
B13       = "2005
C13       = 413.8
D13       = 11626
E13 $     = C13*E40*E41
F13 $     = D13*F47*E41
G13 $     = C13*I48
H13       = SUM(E13:G13)
```

```
I13 I     = H13*K43*253
K13 I     = C13*K43*253
L13       = 11626
M13       = L13*K43*253
N13       = N11*((M13+M18)/(M11+M16))
O13       = N13*N43
A16       = "Offpeak
B16       = "1985
C16       = 40.0
D16       = 3728
E16 $     = C16*E40*E41
F16 $     = D16*F47*E41
G16 $     = C16*I49
H16       = SUM(E16:G16)
I16 I     = H16*(((18-K43)*365)+(K43*112))
K16 I     = C16*(((18-K43)*365)+(K43*112))
L16       = 4467
M16 I     = L16*(((18-K43)*365)+(K43*112))
B18       = "2005
C18       = 273.2
D18       = 8284
E18 $     = C18*E40*E41
F18 $     = D18*F47*E41
G18 $     = C18*I49
H18       = SUM(E18:G18)
I18 I     = H18*(((18-K43)*365)+(K43*112))
K18 I     = C18*(((18-K43)*365)+(K43*112))
L18       = 8284
M18 I     = L18*(((18-K43)*365)+(K43*112))
A21       = "FLYOVER BUILT
C22       = "Delay
D22       = "    Stops
E22 $     = " Idling
F22 $     = "  Stops
G22 $     = "  Pass
H22       = "TOT COST
I22 I     = "ANNUAL
K22 ITR   = "ANNUAL
A23       = "Time
B23       = "Year
C23       = "(hrs)
D23       = "      /hr
E23 $     = "   Cost
F23 $     = "   Cost
G23 $     = "   Cost
H23       = "/hr
I23 I     = "COST
K23 ITR   = "DELAY
A24       = "----
B24       = "____
A26       = "Peak
B26       = "1985
C26       = 43.2
D26       = 2603
E26 $     = C26*E40*E41
```

```
F26 $      = D26*F47*E41
G26 $      = C26*I48
H26        = SUM(E26:G26)
I26 I      = H26*K43*253
K26 I      = C26*K43*253
B28        = "2005
C28        = 138.6
D28        = 4815
E28 $      = C28*E40*E41
F28 $      = D28*F47*E41
G28 $      = C28*I48
H28        = SUM(E28:G28)
I28 I      = H28*K43*253
K28 I      = C28*K43*253
A31        = "Offpeak
B31        = "1985
C31        = 20.4
D31        = 1984
E31 $      = C31*E40*E41
F31 $      = D31*F47*E41
G31 $      = C31*I49
H31        = SUM(E31:G31)
I31 I      = H31*(((18-K43)*365)+(K43*112))
K31 I      = C31*(((18-K43)*365)+(K43*112))
B33        = "2005
C33        = 78.8
D33        = 2993
E33 $      = C33*E40*E41
F33 $      = D33*F47*E41
G33 $      = C33*I49
H33        = SUM(E33:G33)
I33 I      = H33*(((18-K43)*365)+(K43*112))
K33 I      = C33*(((18-K43)*365)+(K43*112))
B38        = " PARAMETERS
B39        = " ----------
B40        = "Idling gal/hr=
E40        = 0.67
B41        = "Dollars/gal=
E41 $      = 1.2
K41        = "Hours/Day
F42        = "Gal/h@50
G42        = "Peak
H42        = "Offpeak
I42        = "$/hr
K42        = "      Peak
M42        = " ACC/YEAR
N42        = "    $/ACC
B43        = "Auto=
D43        = 88
E43 TL     = "%
F43 G      = .01647
G43        = 1.3
H43        = 1.80
I43        = 7.5
K43        = 4
```

```
M43        = 82.75
N43        = 7400
B44        = "Truck
D44        = 6
E44 TL     = "%
F44 G      = .03717
G44        = 1
H44        = 1
I44        = 20.15
B45        = "TracTlr
D45        = 6
E45 TL     = "%
F45 G      = .11682
G45        = 1
H45        = 1
I45        = 20.15
B46        = "Bus
D46        = 0
E46 TL     = "%
F46 G      = F44
G46        = 16
H46        = 5
I46        = 7.5
B47        = "Average
F47 G      = D43/100*F43+D44/100*F44+D45/100*F45+D46/100*F46
H48        = "Peak
I48        = D43/100*G43*I43+D44/100*G44*I44+D45/100*G45*I45+D46/100*G46*I46
H49        = "Offpeak
I49        = D43/100*H43*I43+D44/100*H44*I44+D45/100*H45*I45+D46/100*H46*I46
D51        = "  DELAY
E51        = "  SAVINGS
H51        = " ACCIDENT
I51        = " SAVINGS
K51        = "TOTAL SAVINGS
M51        = "        PRESENT WORTH $
C53 TL     = "  YEAR
D53        = "Current $
E53 TR     = "HOURS
H53        = "Current $
I53        = "    RATE
K53        = "Current $
M53        = "    4%
N53        = "    6%
O53        = "    8%
C55 TL     = "  1986
D55        = I11+I16-I26-I31
E55 G      = (K11-K26)+(K16-K31)
H55 G      = O11*I55
I55        = 0.5
K55        = D55+H55
M55        = (K57-K55)/19*111.56+K55*13.590
N55        = (K57-K55)/19*87.230+K55*11.469
O55        = (K57-K55)/19*69.089+K55*9.8181
H56 G      =
C57 TL     = "  2005
```

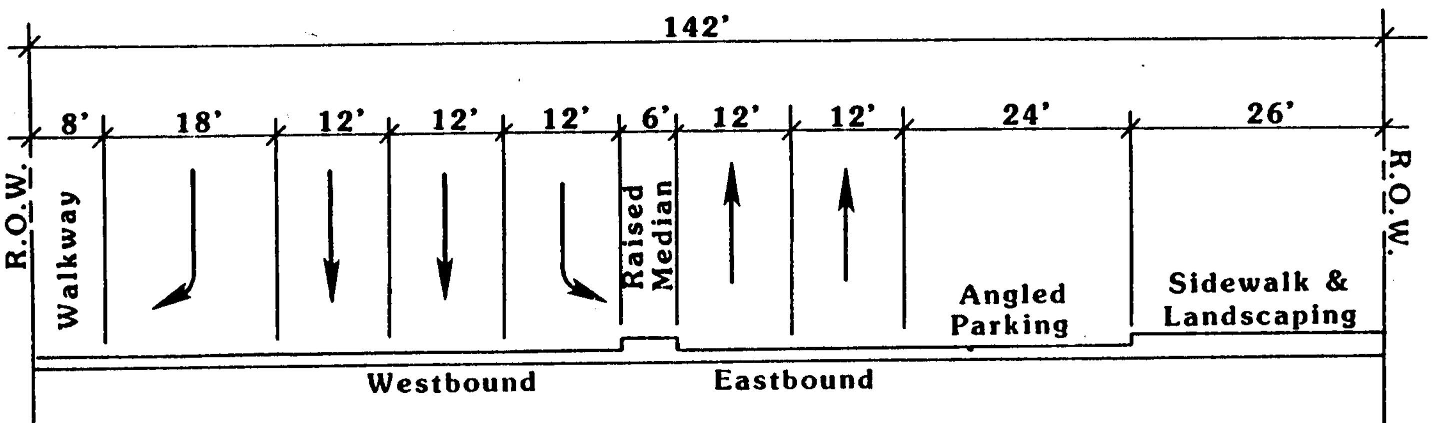
```
D57        = I13+I18-I28-I33
E57  G     = (K13-K28)+(K18-K33)
H57  G     = 013*I57
I57        = 0.5
K57        = D57+H57
D61        = "ANNUAL
E61        = "COSTS
C63        = "Flyover
D63        = "  Year
E63        = " Delay &
F63        = " Accidnt
G63        = " TOTAL
C64        = "yes/no
E64        = " Stops
C66        = "No
D66        = "1985
E66        = I11+I16
F66        = 011
G66        = E66+F66
D68        = "2005
E68        = I13+I18
F68        = 013
G68        = E68+F68
C70        = "Yes
D70        = "1985
E70        = I26+I31
F70        = H55
G70        = E70+F70
D72        = "2005
E72        = I28+I33
F72        = H57
G72        = E72+F72
```

APPENDIX B

Case 7 Cross Sections

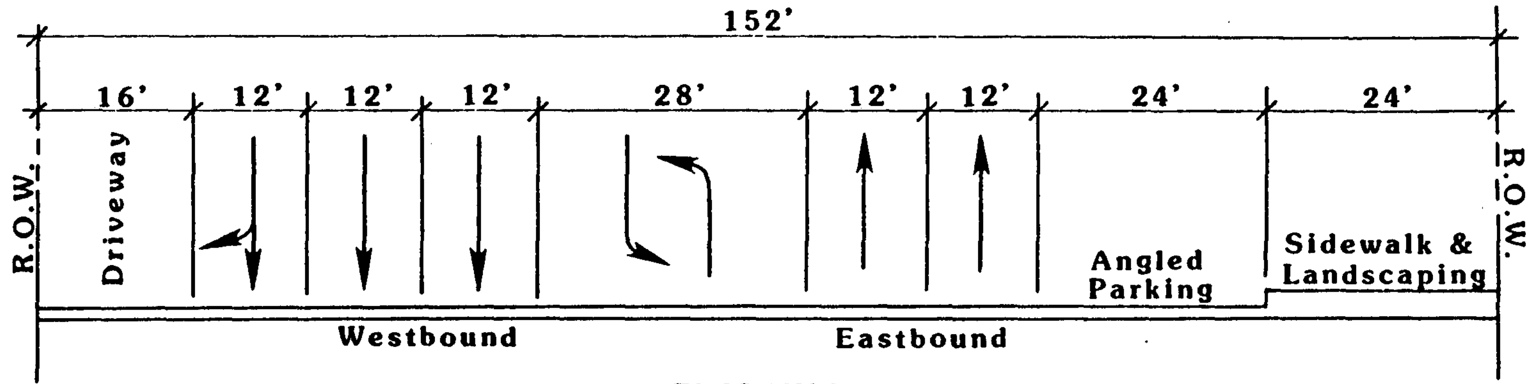
- Various Locations Along Arterial -

SECTION A-A

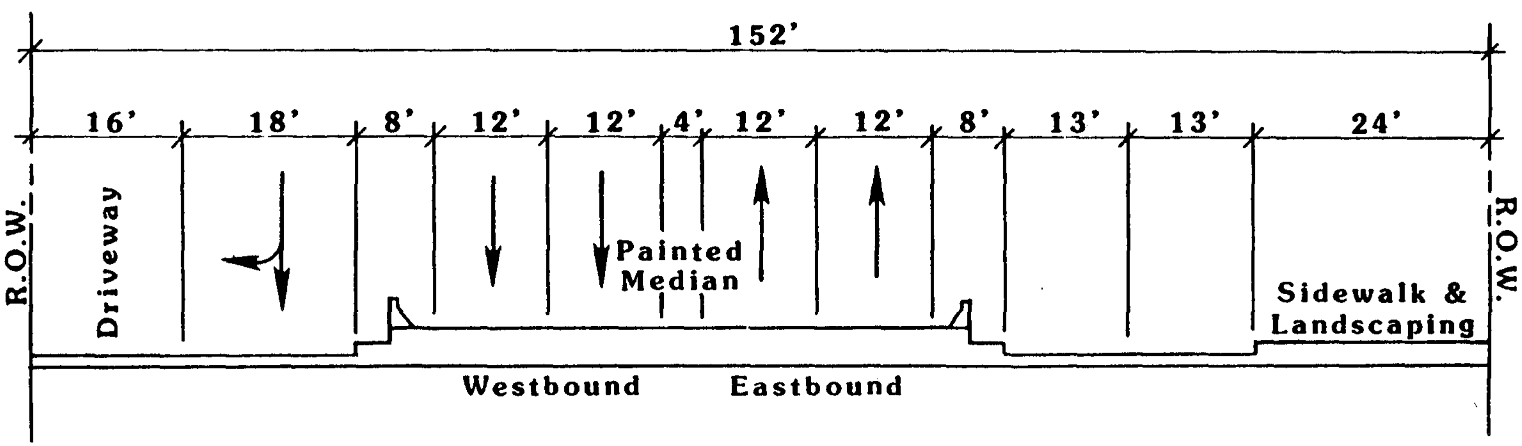


EXISTING

SECTION B-B

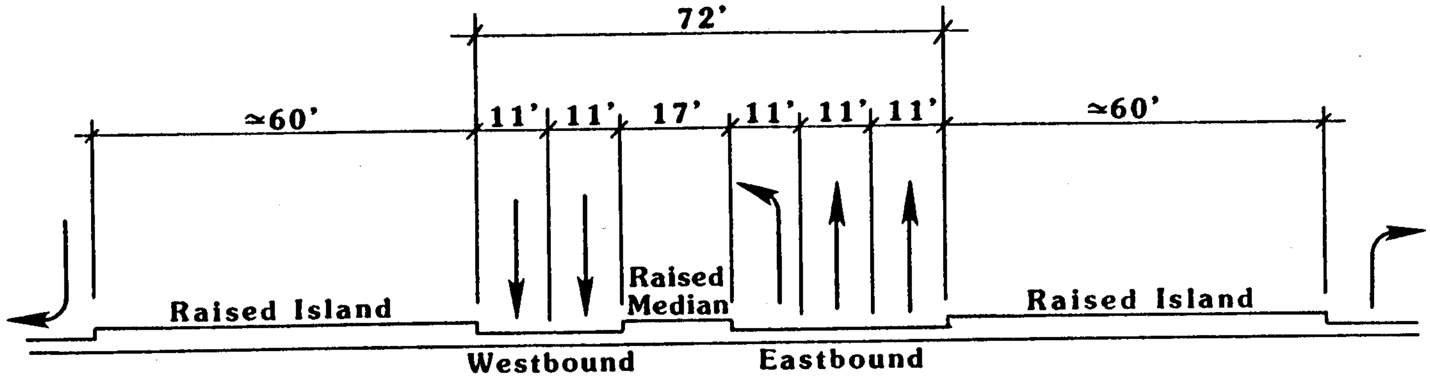


EXISTING

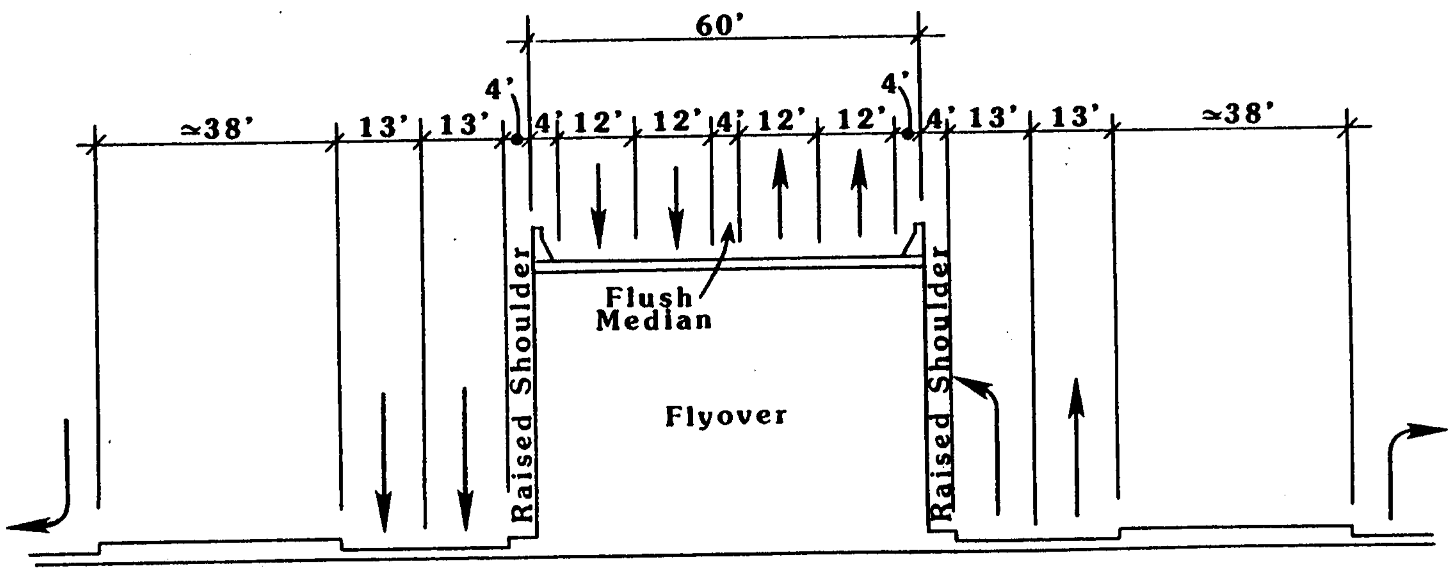


PROPOSED

SECTION C-C



EXISTING



PROPOSED

APPENDIX C

1985 Flyover Unit Costs

Table C-1: Unit Costs

Item	$/ft^2	$/ft	$/yd^3
Bridge - conventional	28.31		
- prefabricated	73.00		
Embankments			
retaining wall - see Figure C-1			
pavement	3.05		
CMB - single		23.00	
- double		29.00	
fill-excavate, transp., compact			12.11
Illumination (on structure only)		36.28	
Signs and Markings (computed along structure length only)		20.00	
Signal estimate assuming existing controller used ($40,000 to $60,000, dep. on structure width)			

	Low	Moderate	High	Very high
Conventional Utility Relocation	100	200	400	800
Conventional Traffic Handling-Const.	50	100	200	400

(Utility and Traffic of prefabricated structure assumed as 1/4 and 1/2 as much as conventional, respectively).

Table C-2. Present Worth Factors Commonly Used In Highway Projects

	Years					
	10		20		30	
i (%)	P/A	P/G	P/A	P/G	P/A	P/G
4	8.1109	33.881	13.590	111.56	17.292	201.06
6	7.3600	29.602	11.469	87.230	13.764	142.35
8	6.7100	25.976	9.8181	69.089	11.257	103.45

Source: (Collier, 1982)

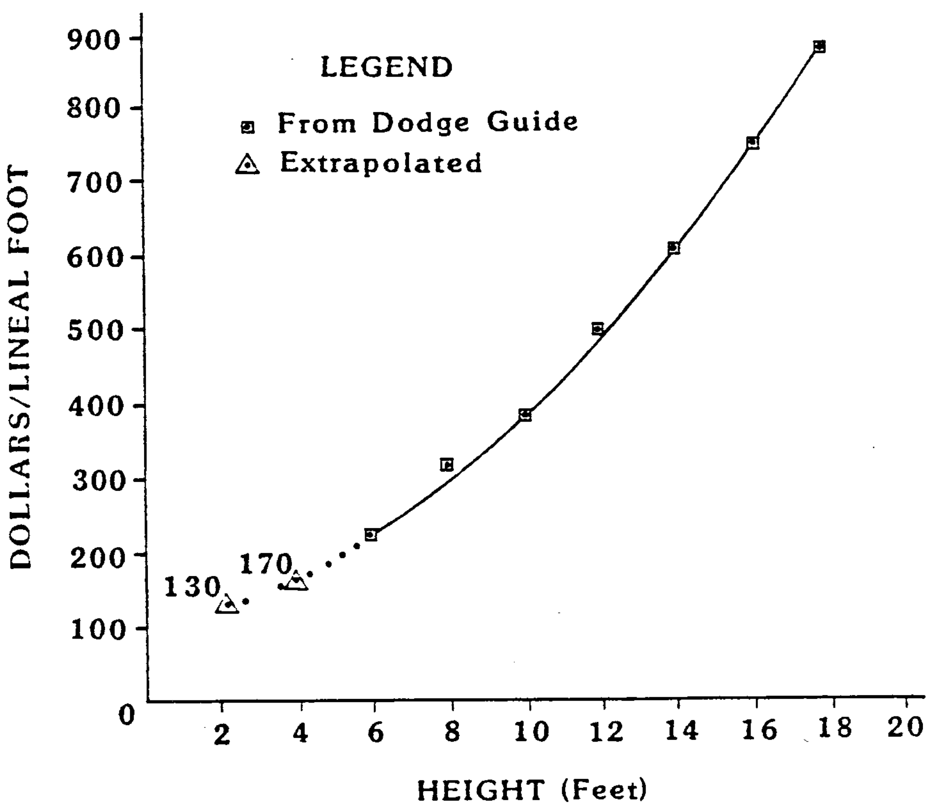


Figure C-1. Unit Cost of Reinforced Concrete Retaining Wall

Source: McMahon, L.A., 1984 Dodge Guide: to Public Works and Heavy Construction Costs, McGraw Hill Princeton, New Jersey, 1983.

APPENDIX D

Manual Procedure to Calculate Present Worth of Savings

Worksheet 1A

Annual Cost of Operations (Peak)

Project ____ Intersection ______________

Peak Period Hours (PPH) ___

Index	Intersection 1st Year	Intersection 20 Year	Flyover 1st Year	Flyover 20 Year
1. Delay Hours [PASSER II]	____	____	____	____
2. Stops/Hour [PASSER II]	____	____	____	____
3. Idling Cost: $'s (1.0 * gal/hr * $/gal)	____	____	____	____
4. Stops Cost: $'s (2. * W2, 1.6 * $/gal)	____	____	____	____
5. Passenger Cost (1. * W2, 2.9)	____	____	____	____
6. Total Cost/Hour (3.+4.+5.)	____	____	____	____
7. Annual Cost: $1,000's (6. * PPH * 253)/1,000	____	____	____	____

Notes: a. PASSER II-84 is source for delay hours and stops per hour.

b. Index numbers are used to identify equation values; a "W" with a number identifies the worksheet

c. Numerical constants are underlined.

Worksheet 1B

Annual Cost of Operations (Offpeak)

Project No. ____ Intersection________________

Offpeak Period Hours (OPH)[1] ____

Index	Intersection 1st Year	Intersection 20 Year	Flyover 1st Year	Flyover 20 Year
1. Delay Hours [PASSER II]	____	____	____	____
2. Stops/Hour [PASSER II]	____	____	____	____
3. Idling Cost: $'s (1.* gal/hr * $/gal)	____	____	____	____
4. Stops Cost: $'s (2.* W2,1.6 * $/gal)	____	____	____	____
5. Passer Delay Cost (1.* W2,2.9)	____	____	____	____
6. Total Cost/Hour (3.+4.+5.)	____	____	____	____
7. Annual Cost: $1,000's (6.* (OPH * 365 + PPH * 112))/1,000	____	____	____	____

[1]Computations are based on an 18 hour day, thus, OPH is 18 - PPH, see worksheet 1A for PPH

Worksheet 2

Average Fuel-Consumption and Delay-Cost

Project No. ____ Intersection ________________

Index	Peak	Off-peak
1. Fuel Consumption Due to Stops		
1.1. Approach Speed (mph)	____	____
1.2. Proportion Auto	____	____
1.3. Proportion Truck	____	____
1.4. Proportion Tractor Trailer	____	____
1.5. Proportion Bus	____	____
1.6. Average[1] (2.*FRS2 + 3.*FRS3 + 4.*FRS4 + 5.*FRS5)	____	____
2. Delay Cost to Passengers		
2.1. Auto Occupancy	____	____
2.2. Truck Occupancy	____	____
2.3. Tractor Trailer Occupancy	____	____
2.4. Bus Occupancy	____	____
2.5. Auto $/pass-hr	____	____
2.6. Truck $/pass-hr	____	____
2.7. Trac Trailer $/pass-hr	____	____
2.8. Bus $/pass-hr	____	____
2.9. Average (1.2.*2.1.*2.5.+1.3 * 2.2 * 2.6 + 1.4 * 2.3 * 2.7 + 1.5 * 2.4 * 2.8)	____	____

[1]FRS is fuel rate per stop cycle for the respective vehicle type, from Table B.1.

Worksheet 3

Annual Cost of Accidents

Project ___ Intersection(s) ___________

Accidents Per Year (APY) ___ Average Accident Cost (AAG)[1] ___

Index	Intersection Peak	Intersection Offpeak
1. Vehicles/Hour		
1.1. 1st Year PASSER II	___	___
1.2. 20 Year PASSER II	___	___
2. Vehicles/Year (thousands)		
Peak: (1.1 * PPH * 253)		
Offpeak: (1.2(OPH* 365 + PPH * 112))		
2.1. 1st Year	___	___
2.2. 20th Year	___	___
3. 20th Year Accident Rate (APY * (2.2 Peak + Offpeak /2.1 Peak + Offpeak))	___	
4. Accident Cost/Year: $1,000's		
4.1. 1st Year (APY * AAC)/1,000	___	
4.2. 20th Year (3. * AAC)/1,000	___	

[1]Recommended values are $5,500 for undivided roadways and $7,400 for divided highways in urban areas, expressed in 1985 dollars.

Worksheet 4

Benefits and Present Worth

Project ____ Intersection ______________

Index	1st Year	20th Year
1. Benefits		
1.1 Delay & Stops: $1,000's (W1A, 7. Intersection - Flyover + W1B, 7. Intersection - Flyover	____	____
1.2 Accidents: $1,000's (W3, 4. * 0.5)	____	____
1.3 Total: $1,000's (1.1 + 1.2)	____	____

2. Present Worth: $1,000,000's
Interest = 8%
(1.3 20th Year - 1st Year /19
* 69.089 + 1.3 1st Year
* 9.8181)/1,000 ____

Capacity of the flyover through lanes is estimated between 1800 and 2000 vehicles per hour per lane (vphpl), depending on the type of shoulders used. Full right shoulders (eight or more feet wide) plus partial left shoulders (three or more feet wide) are assumed to allow 2000 vphpl. Partial shoulders on both sides are assumed to reduce capacity to about 1800 vphpl. Therefore, traffic diverted from the at-grade intersection to the flyover through lanes should be equal or lower than the above limits. Only Case 4 had traffic volumes on the flyover that exceeded capacity and some traffic was assumed to remain at-grade.

At-grade lane capacity or saturation flow rate was based on the PASSER II-84 recommendations (Chang, 1984), such as 1750 vphpl for a through lane and 1700 vphpl for a left turn lane, per hour of green. Restricted storage space or multiple turning lanes reduce these numbers, as explained by Chang. Approach capacity varies based on the amount of signal greentime available for every movement. An ideal at-grade intersection operating with two lanes at each approach, with all traffic moving through and a two phase signal could handle about 3,000 vehicles per hour.

However, approach volumes vary by time of day and direction. Some movements make use of two or more through lanes, left turn vehicles conflict with through vehicles, etc. Volume flowing through an intersection is dependent on several factors that require careful examination. The ability to handle at-grade intersection traffic is another measure of effectiveness output by PASSER II-84.

PASSER II-84 simulates left and through movement, of the four approaches of a typical arterial intersection. Right turn movements are included with the through movements. Movements one through four correspond to the main arterial. Movements five through eight correspond to those of the crossing arterial or street. Table D-1 presents a summary of oversaturated movements based on the X-ratio output by the model.

Results of the Case 1 simulation show some movements with severe congestion with and without the flyover. Main arterial movement 4 will experience severe congestion by year 2005 during peak and off-peak hours. With the flyover this movement will also experience severe congestion only during peak hours. But, since movement 4 volume with the flyover is less than 8 percent of the volume without the flyover, delay is much lower. Cross street movements 5, 6, 7, and 8 also will experience severe congestion by year 2005 during peak periods without the flyover but only movements 5 and 7 will experience such congestion with the flyover. In this case further signal refinement or additional roadway improvements may be required to reduce the severe congestion on movements 6 and 8 (through movements). Movements 7 and 8 which are expected to have severe congestion by year 2005 during off-peaks, observe a reduced level of congestion with the flyover.

Case 2 experiences congestion only during peak periods without the flyover. No congestion is predicted with the flyover.

Case 3 experiences congestion during peak and off-peak periods without the flyover. Severe congestion is foreseen on the cross street movement 5 with the flyover. However, the low congestion on other approaches allows fine tuning of cycle length to reduce this condition to the point of being negligible.

Case 4 shows congestion with the flyover by year 2005. If the traffic volumes forecast for this intersection are realized, there is going to be congestion at this intersection regardless of improvements within the right-of-way. As before, PASSER II may be favoring some movements at the expense of others and manual adjustments to the green time may be required.

Partly, the indicated level of congestion is a function of the way PASSER II minimizes delay; once an approach movement is assigned the maximum allowed delay (130 seconds per vehicle for cycles above 100 seconds) the movements with higher demand may be favored in order to reduce total delay. Manual adjustment to the minimum green may be required for a more balanced solution; however, this will not solve the congestion problem. For the sake of uniformity in the procedure, the minimum delay cycle indicated by PASSER II-84 has been selected.

Table D-1. PASSER II-Defined-Movements Experiencing Congestion (LOS"F")

Case No	Flyover (Yes or No)	Period & Year	Main Arterial X 1.0 .5	Main Arterial X 1.5	Cross Street X 1.0 1.5	Cross Street X 1.5
1	No	Peak 1985			7,8	
		2005	2	4		5,6,7,8
		Off pk 1985				
		2005	2	4		7,8
	Yes	Peak 1985				
		2005	2	4	8	5,7
		Off pk 1985				
		2005	4		5,7	
2	No	Peak 1985				5,6,7,8
		2005	3,4		5,6	8
		Off pk 1985				
		2005				
	Yes	Peak 1985				
		2005				
		Off pk 1985				
		2005				
3	No	Peak 1985	4			5
		2005	1,2	3,4		8
		Off pk 1985				
		2005	3,4		8	
	Yes	Peak 1985				5
		2005				
		Off pk 1985				
		2005				
4	No	Peak 1985				8
		2005		2	7	8
		Off pk 1985				
		2005			5,6	
	Yes	Peak 1985				
		2005	3	2	7,8	
		Off pk 1985				
		2005				
5	No	Peak 1985				
		2005			5,6	
		Off pk 1985				
		2005				
	Yes	Peak 1985				
		2005				
		Off pk 1985				
		2005				
6	No	Peak 1985				
		2005	C=3,4		C=5,6	A=5,6
		Off pk 1985				
		2005				
	Yes	Peak 1985				
		2005				
		Off pk 1985				
		2005				
7	No	Peak 1985				
		2005	4		7,8	
		Off pk 1985				
		2005				
	Yes	Peak 1985				
		2005				
		Off pk 1985				
		2005				